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Enhancing the Quality of U.S. Grain for International Trade

Volume II -- Background Papers

Part B (2nd section): Technologies Affecting Quality

7. Fumigation and Other Insect Management Interventions
8. Alternative Grain Transportation and Distribution Technologies and Their Impact on Grain Quality
9. Grain Quality Attributes for Corn Dry Milling
10. Grain Attributes for the Feed Industry
11. Technology for the Inspection of Corn, Soybeans, and Wheat

August 1989

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Paper No.

7. Fumigation and Other Insect Management Interventions by Hagen B. Gillenwater and Robert Davis
8. Alternative Grain Transportation and Distribution Technologies and Their Impact on Grain Quality by C. Phillip Baumel
9. Grain Quality Attributes for Corn Dry Milling by Marvin R. Paulsen
10. Grain Attributes for the Feed Industry by Tilden W. Perry
11. Technology for the Inspection of Corn, Soybeans, and Wheat by Charles R. Hurburgh

Background Paper No. 7

Fumigation and Other Insect Management Interventions

Hagen B. Gillenwater and Robert Davis
Agricultural Research Service
U.S. Department of Agriculture
Savannah, GA

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Office of Technology Assessment
U.S. Congress

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FUMIGATION AND OTHER INSECT MANAGEMENT INTERVENTIONS

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General Introduction

Economic losses in stored products are a complex of absolute losses and those depending on social standards (Howe, 1965). These losses are real, but other than quantitative losses, they are very difficult to measure or even in many instances to estimate. Other types of losses would include nutritional, quality, viability and damage. Insects contribute to all of these types of losses to varying degrees, often significantly. Through their presence, their feeding, and their excretions, they cause or create conditions favorable for other organisms to cause losses worldwide ranging upward to 30-40% of that produced (May, 1977).

In today's commerce of agribusiness's worldwide marketing of grain and grain products, insect infestations can easily travel throughout the world unless a conscientious effort is made to apply effective control interventions. With our present level of technology, the proper use of a fumigant is usually the only available and entirely satisfactory method of ridding grain of live insects and mites. The inability to penetrate grain depths, available time for an application and kill, quantity to be treated and cost of the product and labor severely limit the use of interventions other than fumigants.

Fumigants originally were any substance which, when burned, produced acrid smoke or fumes. The use of such smokes are referenced in the writing of antiquity by Homer and Pliny.

Primitive peoples of Asia, Africa and the Middle East long have used the smoke of their cooking and heating fires to assist in warding off insect infestation of the stored grains. Today in Kenya on subsistance farms, corn is usually stored with the leaf sheaths intact on a wooden platform above the fireplace where it is exposed to the smoke and heat (Muhihes and Kibata, 1985).

The first use of a modern fumigant was that of hydrocyanic acid gas to control scale insects on citrus trees in California in the 1880s. Fumigants available and approved for pest control in grains during the second and third quarters of this century were almost entirely composed of varying percentages of carbon tetrachloride, carbon disulfide, ethylene dichloride and ethylene dibromide. Today our only available grain fumigants are hydrogen phosphide (phosphine), methyl bromide, chloropicrin, atmospheres enriched with carbon dioxide or nitrogen and atmospheres depleted of oxygen.

The control of pests in grain storage facilities and transportation vehicles is an economic driven model. If it costs money it will in all likelihood not be undertaken unless it will prohibit the sale of the grain. This statement is valid not only for the use of pesticides but for the use of aeration, turning, cleaning or any other manipulation to the grain to control damage and/or prevent the loss of quality. While such an approach is an option in a free market it can result in situations where pest build up can reach such proportions that preventive approaches such as aeration, turning and the applications of residual pesticides as grain protectants and space sprays will no longer work at an acceptable level. It is at this time that an emergency or corrective action, such as the use of a fumigant, is required.

It should be stressed that other types of pest interventions are available, effective and if timely applications are made, will reduce the need for fumigants, but not to the extent we could do without fumigants in our pest control arsenal. Cleaning and spraying of combines, transportation vehicles before harvest and treating storages with residual pesticides is highly recommended. The use of residuals is also recommended as a protectant applied directly to the grain as it is being binned or transferred if not previously treated. The use of a program of residual sprays and grain protectants with hygienic procedures were the mainstays of a Clean Grain Program that was USDA sponsored in the 1950's which proved highly successful (Gates and Gage, 1978; Appendix-A, and Federal Extension Service, 1955; Appendix-B.).

If the United States is to remain competitive in the world trade of grain with Canada, Australia, Argentina and the European Community it will be essential that we have safe and effective chemicals for use as admixtures and space sprays as well as for fumigants. Of our competitors, only Canada has a climate that will allow for grain storage with minimum chemical applications for pest control. Therefore it is incumbent upon research to continue diligently in its search for new chemicals and application methodologies for existing chemicals that will be safe to apply, safe for the consumer and toxic to the pests.

Current State of the Art

Treatments of Storage Facilities

Most grain storage facilities provide an ideal habitat for stored-grain insects even when the facility is empty. Residues of grain in floor cracks and crevices, wall and ceiling voids and ledges provide an ample supply of food to sustain several species of insects until the facility is filled with newly harvested grain. Sweepings and spillage in the vicinity of storage facilities and especially, grain particles that filter through cracks to spaces beneath a storage facility provide excellent sources of infestation of newly stored grain.

Thorough cleaning is the first and most effective step toward preventing insect infestation of newly harvested grain. Because insects live from season to season in and around grain storage facilities, the importance of cleaning and removal of trash and litter can not be overemphasized. Also, a thorough cleaning should precede any insecticidal treatment if the full value of the treatment is to be expected. Contrary to some opinions, an insecticidal treatment is not a substitute for good sanitary practices.

After cleaning, the surfaces of grain storage facilities, such as walls and floors that will come in contact with the grain, should be sprayed with a residual type insecticide. Insecticides labeled for this purpose include malathion, and chlorpyrifos-methyl (Reldan(R)), organophosphate compounds, synergized pyrethrins, an extract of a plant species of chrysanthemum, and methoxychlor, a chlorinated hydrocarbon (Appendix-C). Malathion is most often used because it is inexpensive and is well known through long usage. Formulations of each of these insecticides may be available as emulsifiable concentrates (EC), wettable powders (WP), or as sprayable microencapsulations. Mixing and application instructions are provided on the label.

Grain Protectants

The term "grain protectant" refers to the application of an insecticide to the grain as it is conveyed into storage. The application is expected to provide an insecticide residue on the grain that will protect it from insects during a regular storage season. When properly applied, a grain protectant should (1) prevent or minimize additional damage by an existing infestation and (2) more importantly, protect uninfested grain from becoming infested.

In addition to several insecticides, grain protectants now available include an insect pathogen and several inert dusts. The insecticides are synergized pyrethrins and malathion which have been in use for many years. In 1986, two organophosphate insecticides, pirimiphos-methyl, and chlorpyriphos-methyl, received limited approval for use as grain protectants. Each of these four insecticides are formulated as emulsifiable concentrates (the formulation preferred by most users), wettable powders, and as dusts. Instructions for mixing with water and rate of application to the grain are given on the manufacturer's label and labeling.

Insect infestations of stored grain usually involve a complex of insect species, and each species and life stage differs in its susceptibility to an insecticide/fumigant (Gillenwater and Burden, 1973; Harein, 1982). Therefore, the dosage of an insecticide/fumigant applied must be directed against the least susceptible life stage.

Some important performance characteristics of insecticides currently available as grain protectants or residual-type treatments are as follows:

Pyrethrins are the six insecticidal esters extracted from pyrethrum flowers, a plant species of chrysanthemum, thus the plural reference to the insecticide. When synergized with piperonyl butoxide in a ratio of 1:10 (pyrethrins: piperonyl butoxide), the insecticide qualities of pyrethrins are greatly increased. For many years, synergized pyrethrins was the only insecticide approved for use as a grain protectant. Consequently, it has a long history of safe usage. Pyrethrins are both toxic and repellent to many species of insects. Because it tends to loose its toxicity rapidly, its efficacy as a grain protectant is apparently from repellency.

Pyrethrins may be the oldest of our modern insecticides. It was introduced into the United States about 1860 (Gnadinger, 1936). Through there are many formulations available as grain protectants, none are approved for use on stored soybeans.

Several factors have limited the use of pyrethrins as a grain protectant during the past 15 to 20 years:

1. The pyrethrins extracts are imported, primarily from Kenya. Thus, for various reasons, the supply is not as reliable as desired.
2. With the approval of malathion as a grain protectant, pyrethrins were no longer competitive economically.
3. In general, pyrethrins lacked the biological efficacy desired as a grain protectant (less than 100% kill of some species and life stages) that appeared promising with the use of malathion.

It is well known that pyrethrins has a rapid "knock down" effect on most species of insects. However, this does not mean that the insects are dead; in fact, they may recover with no apparent detrimental effect (Lloyd and Hewlett, 1958).

With the many years of use of pyrethrins as an insecticide.

insects have developed little or no resistance to it. Where resistance has been indicated, researchers attribute little importance to it.

Malathion, an organophosphate, has been the insecticide of choice as a grain protectant for more than 20 years, but it is not approved for use on soybeans. It is highly effective against most species of grain-infesting insects and it has a long history of safety to man and the environment. Though malathion has been used successfully as a grain protectant for many years, convincing evidence of insect resistance to malathion was being reported in the mid to late 1960's (Parkin, 1965, Speirs et al., 1967, and Speirs and Zettler, 1969). During the last 15 years, researchers have reported alarmingly high levels of insect resistance to malathion (Zettler et al., 1973; Zettler, 1982). Because there was and continues to be no practical/economical alternative, malathion continues to be the grain protectant of choice. In some cases, it is doubtful that malathion is of any value as a grain protectant.

Pirimiphos-methyl (Actellic $^{(R)}$), is an organophosphate, recently introduced to the post harvest grain market. It has a relatively low mammalian toxicity (acute oral LD50 to rats of 2,050 mg/kg, which is comparable to malathion at 2800 mg/kg). It controls a wide range of insect species including those resistant to malathion. In 1986, pirimiphos-methyl was approved for export only for use as a protectant on corn and wheat (but not soybeans).

In 1987, it was approved for domestic use on corn. It is approved for use, however, on stored grains in 14 foreign countries (ICI Americas Inc., 1986).

Chlorpyrifos-methyl, is an organophosphate, also recently introduced to the post harvest grain market. The Reldan 4E (4 lbs/gal emulsifiable concentrate) has a mammalian toxicity of 1530 mg/kg oral LD 50 to female rats. It controls a wide range of insects that infest stored grain including those species resistant to malathion. In 1986 it was approved for use as a grain protectant on wheat (but not on corn and soybeans). A dust formulation containing 3% chlorpyrifos-methyl was approved for use as a protectant for wheat and corn (but not soybeans).

Bacillus thuringiensis (BT), a bacterium, is the only insect pathogen used as a grain protectant. Spores of the bacterium are prepared as dust or water suspension formulations. To be effective the spores must be ingested by the insects. Also, only the moth species of grain pests are controlled by BT. BT provides little or no control of grain infesting beetles and weevils. When moth infestations occur, they are on or near the surface of the grain. Therefore, for both practical and economic reasons, the BT is (1) admixed with the last 4 to 6 inches of surface grain as it is placed in storage or (2) sprayed on the surface of the grain after the storage is filled. BT is exempt from the requirement of a tolerance for residue.

Inert dusts, such as silica aerosols, magnesium oxide, aluminum oxide, diatomaceous earths, and clays have varying degrees of potential as grain protectants. In general, they are slow acting as they kill insects mainly by an abrasive action which results in dessication of the insect. They do not perform well in moist grain or in high moisture conditions. Relatively little use has been made of inert dust for protecting grain in the US (Harein, 1982). Most storage elevator operators are reluctant to add dust to an already too dusty condition. Other disadvantages may outweigh the value of inert dusts, such as environmental contamination, damage to machinery by its abrasive action, increased risk of fire, lung damage to workers, and reduced grade and/or test weights of the grain.

Fumigation

In today's concept of "fumigation," the word is a misnomer. Perhaps because of this misnomer many people have the misconcept that any application of fine particles of an insecticide into an enclosure or building as an aerosol, fog, mist, or smoke is to "fumigate." Therefore, it is important to define the modern terminology of "fumigant" and "fumigation" and to emphasize that fumigation is a separate technology for insect control from other chemical control methods. In his "Manual for Fumigation for Insect Control," Bond (1984) gives a classical definition as follows: "--a fumigant is a chemical which, at a required temperature and pressure, can exist in the gaseous state in sufficient concentrations to be lethal to a given pest organism."

This definition implies that a fumigant acts as a gas in the strictest sense of the word, that it can penetrate into the materials being treated (even into individual kernels of grain) and then be removed by aeration. It should follow then that fumigation is the highly specialized art of applying some of the most toxic and unique pesticides that requires professional personnel who are well trained and experienced regarding both the fumigant and the target organism.

Fumigants Currently Available: Only three compounds, methyl bromide, hydrogen phosphide, and chloropicrin are presently available as grain fumigants except chloropicrin is not approved for use on soybean and its use may be limited by EPA to the fumigation of empty facilities in the near future. Of these three compounds, hydrogen phosphide is the fumigant of choice for fumigating grain.

Some fumigators consider dichlorvos, an organophosphate insecticide with a high vapor pressure as a fumigant. However, it does not penetrate into the product being treated; therefore, it does not fit the major definition and performance requirements of a true fumigant. It is used effectively as a "space" fumigant as it can be vaporized into a storage facility to treat the free space around or above the stored grain and other products. For the purpose of this report, dichlorvos will not be considered as a grain fumigant.

The performance characteristics of the available grain fumigants can be assessed best by comparing them to characteristics of an ideal fumigant as follows: 1) Highly toxic to all life stages of the target insects; 2) Relatively nontoxic to man and his animals; 3) Highly volatile with good penetrating ability; 4) Noncorrosive to metals; 5) Nonflammable or explosive under practical conditions of usage; 6) Nonreactive with the commodity (does not produce an adverse flavor, aroma, or residue); 7) Has no effect on seed germination; 8) Economical, readily available, and simple to apply; 9) Fast acting, aerates quickly, and has no adverse effect on the environment; 10) Easily detected and has adequate warning properties.

Unfortunately, there is no ideal fumigant. However, each of the available grain fumigants possess some of (or some degree of) these characteristics. Therefore, it is very important for the fumigator to be well informed on the performance characteristics of each fumigant so that he may perform a safe and effective fumigation.

Methyl bromide, is highly toxic to the life stages of grain-infesting insects. Because it has been available for many years (early 1930's), there are many schedules that give very specific times, temperatures and dosages for effective fumigation of a wide variety of products and pest organisms. Most grain fumigation schedules specify 24 hours with dosages adjusted according to the grain temperature.

Methyl bromide is highly toxic to man and his animals. Because it is essentially odorless, extreme care is necessary to avoid exposure. Even sublethal exposures may cause neurological symptoms. Exposure of the skin to the liquid phase may cause severe blistering. The Threshold Limit Value (TLV)$^{(R)}$ is 5 ppm in air (ACGIH, 1987).

Methyl bromide is packaged in cans (1 and 1-1/2 lb sizes) and in various sized steel cylinders. As it is a liquid under pressure (boiling point of 3.6°C [38.5°F]) it is highly volatile, but to achieve good penetration of grain forced recirculation is generally required.

Methyl bromide is an excellent solvent of many organic materials, especially natural rubber. Methyl bromide gas is noncorrosive to metal, but the liquid phase reacts with aluminum in the absence of oxygen to form a compound that ignites spontaneously in the presence of oxygen.

Methyl bromide is neither flammable nor explosive under practical conditions of fumigation. In fact, it has been used effectively as a fire extinguisher. In the presence of a flame, such as a pilot light, methyl bromide decomposes into hydrobromic acid which is very corrosive to metals.

Methyl bromide reacts with most food commodities and grains to produce inorganic bromide residues. These residues are permanent and are accumulative with each additional fumigation of the same product. It is also reactive with a host of other nonfood items, especially those that contain reactive sulphur compounds. The degree of reaction with a product is relative to the dosage applied, temperature of the product, the duration of fumigation period, and the number of times the product is fumigated. Thus, when the inorganic bromide tolerance is exceeded, adverse flavor or aroma of the product or both may occur. Some loss of viability or delay in seed germination may be expected with methyl bromide fumigation of seeds and methyl bromide soil fumigations can be used to destroy the viability of noxious seeds.

Methyl bromide is probably economically competitive with other fumigants. It is readily available to authorized personnel. The application of methyl bromide requires special equipment both for application and safety. Because it is a liquid under pressure, knowledge and experience in using the equipment is essential. The requirement of special equipment to provide recirculation of methyl bromide places a substantial limitation on the use of methyl bromide as a grain fumigant. Such equipment is expensive and only practical to use in facilities that are sufficiently gas-tight to prevent loss of the gas caused by the positive pressure of the recirculation system.

Methyl bromide is considered to be as fast acting as most fumigants and fumigations can be accomplished within 16 to 24 hours. Because methyl bromide treatments can be conducted under the "concentration times time" (CxT) concept, the actual duration of fumigation can be rather flexible. That is, the same biological efficacy can be achieved by maintaining a low concentration of gas and increasing the time or by maintaining a high concentration and decreasing the time of fumigation. Many schedules based on the CxT concept of methyl bromide fumigation are available for a variety of products.

The recirculation system used during the application of methyl bromide may also be used to aid in the aeration. Most of the unreacted methyl bromide is aerated within 3 to 4 hours; however, atmospheric aeration should continue for 48 hours or more or until the concentration has been reduced to a safe level (0.3 ppm). During the initial period of aeration, care must be exercised to avoid exposure of personnel opening the facility and anyone in the immediate vicinity. The gas is rather quickly diluted with fresh air to undetectable levels or to levels below the TLV. A wide range of methyl bromide concentrations can be easily detected by use of a halide lamp, a device commonly called a halide leak detector. This detector is used extensively to detect leaks during fumigation. Other more sensitive and sophisticated devices such as detector tubes and thermal conductivity analyzers are used frequently. As methyl bromide is practically odorless at low levels that are dangerous to humans, it is without adequate warning properties.

Hydrogen phosphide, is probably the fumigant of choice for most grain fumigations within the foreseeable future. It falls short of the ideal criteria, but is has many usable qualities not available in any other fumigant. It is highly toxic to all life stages of grain infesting insects. It is very toxic to man and his animals and exposure may be by inhalation or ingestion but not through the skin. The inhalation TLV is 0.3 ppm for applicators based on an 8-hour time weighted average (TWA) during application. After application, exposure may not exceed 0.3 ppm at any time.

Hydrogen phosphide is highly volatile with an excellent penetrating quality into grain and other products. It is formulated chemically as a solid either as aluminum or magnesium phosphide. Gas is released when the formulation is exposed to atmospheric moisture. Formulations are marketed as tablets, pellets, granules (held in moisture permeable sachets), and flat plates (a granular form of magnesium phosphide embedded in a plastic matrix).

Hydrogen phosphide is corrosive to certain metals such as copper, gold, silver, etc. Therefore, such items as electrical appliances, and electronic equipment, must be protected or removed from facilities being fumigated.

Hydrogen phosphide can be highly flammable or even explosive under conditions of misuse, such as applications resulting in extremely high concentrations of the gas. The lowest explosion point is 17,900 ppm in air. However, concentrations of 300-500 ppm are adequate for most fumigations. Hydrogen phosphide can be considered safe under all practical conditions of usage.

Hydrogen phosphide does not react with grain to cause either adverse flavor or aroma nor excessive residues. The residue tolerance for grain is 0.1 ppm. Hydrogen phosphide does not affect seed germination. It is economical, readily available, and the simplest type of fumigant to apply. A formulation can be simply scattered randomly or placed systematically on the surface of the grain or it can be submerged into the grain by using tubular probes or by simply stepping on the formulation scattered or placed on the surface. Though not required, but if the grain surface was then covered with a film (such as polyethylene) the distribution and performance of the fumigant would be enhanced.

Rapid distribution of gas in storage facilities can be achieved by mechanically metering tablet or pellet formulations into the grain stream during binning. Layering techniques and piping systems have been developed to increase gas distribution in ships during transit. Hydrogen phosphide is not a fast acting fumigant if compared to methyl bromide. Most labels of hydrogen phosphide formulations specify from 3 to 5 days or longer depending on the temperature for fumigating a wide variety of products. However, much longer periods of fumigation are usually required when large masses of grain are to be fumigated (Davis, 1982). The fumigating duration will begin when the distribution of the hydrogen phosphide is complete.

With cross ventilation, hydrogen phosphide is removed from the free space of a storage facility rather quickly; often within minutes. Low levels of hydrogen phosphide gas may continue to evolve from the grain, but by continuing the cross ventilation, workers can enter the facility and even work on the grain surface. Because hydrogen phosphide has about the same density as air it dilutes quickly with fresh air. After the initial period of ventilation it can seldom be detected except within the grain mass. When released after fumigation, hydrogen phosphide has no known adverse effect on the environment.

Hydrogen phosphide is easily detected by use of detector tubes which are available from several manufacturers. Detector tubes are available for measuring both high and low level concentrations; high levels as during fumigation and low levels as monitoring for personnel safety.

The odor of hydrogen phosphide, often described as carbide or garlic-like, can be detected at very low levels. Although the odor can be a usable warning property, most fumigators understand that the odor may not persist throughout a fumigation to provide an adequate warning during aeration.

Chloropicrin is a strongly irritating lachrymator that is highly toxic to all the life stages of grain infesting insects, and it is very toxic to man and his animals. Exposure to a concentration of only 360 ppm in air is said to cause death in 1 minute. A concentration of 6000 ppm may be achieved during grain fumigations, whereas a concentration of only 1 ppm in air is an intensely irritating gas to humans.

With a boiling point of 112°C, chloropicrin is difficult to volatilize. Several methods have been devised to achieve vaporization, but evaporation of the liquid or mixing with methyl bromide and dispensing as an aerosol have been used effectively. To achieve penetration and distribution within the grain, some form of recirculation is generally required.

Chloropicrin is corrosive to metals, especially in the presence of moisture. However, it is neither flammable nor explosive and does not react with the grain to cause permanent residues or any adverse flavor or aroma. It can be used to fumigate seeds without affecting germination.

Chloropicrin is economical to use and is readily available. Though it is a liquid, but not under pressure like methyl bromide, the equipment and technology required to apply chloropicrin are similar. Also, like methyl bromide, chloropicrin is fast acting against grain infesting insects, but it is slow to aerate. In fact, it may be unpleasant to handle some commodities for several days after fumigation. Its severe toxicity to plants may be the greatest effect of chloropicrin on the environment. However, with reasonable care during aeration, plant injury can be avoided.

Fumigation Safety/Hazards: Each of the available fumigants is a "restricted use" pesticide and has safety hazards that must be taken into account if it is to be utilized safely and effectively. Because of the magnitude of these hazards, the wise fumigator will utilize a well defined checklist of procedures to follow throughout the fumigation. A very detailed checklist available to fumigators is published by the National Pest Control Association, Inc., (1982) in their series of "Good Practices" statements entitled "A Checklist for Fumigation." This checklist stresses the (1) importance of planning and preparation for each fumigation and lists items that a well planned fumigation should include, (2) quality of personnel required to carry out the plan with emphasis that workers utilize the two-man-buddy system as a special safety factor, (3) the importance and type of protective equipment with emphasis on the limitations and proper use of the equipment, (4) adherence to application procedure and fumigation period provided by the manufacturer's label and labeling, and (5) importance of safety during post fumigation procedures, especially that the release of the gas will cause no hazard and empty containers and related materials will be removed and disposed of properly.

Types of Fumigations Performed: Among the chemicals used as insecticides on stored grain, fumigants are probably the finest tools available. Also, both researchers and applicators will agree that fumigation is the last line-of-defense when all other insect control methods fail. It should be understood by all concerned that special care should be exercised to avoid any misuse of the available registered fumigants that may lead to their cancellation by regulatory authorities or to their loss of effectiveness due to the development of insect resistance. The technology is available that makes it possible to achieve 100% kill of the target organism. Because of the diversity of storage facilities and conditions under which fumigation is needed or desired, 100% kill is seldom achieved. Therefore, we can identify two major types of fumigation being practiced today as (1) commercial or economic control where something less than 100% kill is often achieved and (2) quarantine-type fumigations where every effort is made to achieve 100% kill.

Commercial/economic control fumigations. Most fumigations of grain are of the commercial or economic control type. That is, enough of the insects are killed to minimize economic losses and make the grain acceptable to the buyer. This method of fumigation is accepted because most storage facilities are not sufficiently gastight to retain the fumigant and the cost of sealing the storage for gastightness may not be economical or the economics understood. This type of fumigation is often accepted where very large masses of grain are involved or time available is limited, such as in large elevators and export grain in the holds of ships. While some of these facilities may be adequately gastight, the technology of achieving distribution of the fumigant gas throughout these masses of grain has not been adequately researched and developed, resulting in less than complete control.

When the number of adult insects infesting grain are sufficient to require fumigation, there is a much greater number of immature insects living inside individual kernels of the grain. Thus, when a commercial or economic control fumigation is conducted many of these immature insects are not killed. Though the grain may pass formal inspection by the USDA, Federal Grain Inspection Service (FGIS) as not being infested, many of the immature insects that develop within the kernels will emerge as adults within the next 2 to 4 weeks and the grain is found to be reinfested. Two important problems arise from this type of fumigation as follows:

1. Grain certified as not being infested may arrive at destination infested.
2. Insects not killed by the fumigation are exposed to

sublethal dosages of the fumigants which is the basis for the development of resistance. Insect resistance to any of our registered fumigants, means a major loss in our last-line-of-defense.

Quarantine-type fumigation

The objective in quarantine-type fumigation is to achieve complete kill of all life stages of the target organism. Methyl bromide is the fumigant of choice, as the USDA, Animal and Plant Health Inspection Service (APHIS) has developed schedules based on the (CxT) concept of fumigation. These schedules are given in the Agricultural Quarantine Treatment Manual (USDA, 1976) which covers a wide variety of products and pest organisms.

Variations in Application Procedures

The types/quality of grain storage facilities varies greatly, especially farm storage facilities. These may range from loosely constructed wooden or metal bins that provide little or no physical protection against insects to well constructed metal bins or concrete silos that are designed to minimize pest problems. The poorly constructed facilities, usually associated with small farms, have been generally suitable for fumigating grain with liquid fumigants. Liquid fumigants were various mixtures of chemical solvents such as carbon tetrachloride, ethylene dibromide, ethylene dichloride, carbon bisulfide and chloropricrin that were poured, sprinkled or injected into grain to control insect infestations. Most of these liquid fumigants are no longer available. It is questionable whether some of these poorly constructed facilities can be sealed adequately and economically to retain a fumigant gas such as hydrogen phosphide. In some cases, a fumigator may be advised to increase the fumigant dosage to compensate for gas leakage. This is an erroneous approach and the label or labeling does not advocate this procedure. The practice of increasing the fumigant dosage to compensate for leakage or failing to adequately seal a storage facility to retain the fumigant gas will result in control failures and can lead to insect resistance and ultimately, to the loss of the fumigant.

Farm Storage Facilities: For several reasons such as a remoteness of farm storage facilities, small amount of grain to be treated, storage facilities are inadequate to receive an insect control treatment, and lack of information, most farm-stored grain may never receive a properly applied insect control intervention. Therefore, when this infested grain is marketed, it becomes mixed with noninfested grain and inflates the magnitude of the problem within the marketing channels. In their study of farm stored grain in Minnesota, Barak and Harein (1981) stated: "It is likely that much infested grain goes undetected and is later commingled with sound grain, thus creating greater loss and the need for more expensive and time consuming remedies at a later time."

Country Elevator/Cooperative Storages: Although there are many good quality, on-farm storage facilities where good pest management practices are conducted, the well constructed facilities that utilize pest management technologies in their design are found deeper in the grain marketing system. These locations include country elevators and cooperative storages, processing plants, and port elevators where large quantities of grain are handled.

The two basic types of storage structures are flat and upright. They are usually equipped with some type of forced aeration for cooling and drying the grain. These aeration systems are not designed for recirculation as needed for fumigation with methyl bromide; however, in some cases storage facilities can be equipped with a reasonable amount of "plumbing" to effect a recirculation system.

Flat storage. Flat storages may be constructed of metal, wood, or concrete or a combination of these materials. Flat storage facilities discussed here are of a rectangular configuration that can be used for storage of bags, boxes or bulk grain or other products. Most of these facilities are not adequately gastight for fumigation of bulk grain with any of the available fumigants. While they were available, liquid fumigants often were used because a minimum amount of sealing was needed to achieve a relatively good insect control treatment. In a flat storage facility not suitable for fumigation, a protective treatment could be used effectively.

Flat storage facilities that are adequately gastight can be fumigated with one of the hydrogen phosphide formulations. In such cases, the surface of the grain is leveled and the fumigant formulation is inserted to various depths into the grain by use of probes. A near ideal type of flat storage structure is described in FAO Plant Production and Protection Paper No. 63 (1985). It is designed for gastightness and protection against insects and other pests.

Upright storage. In general, upright storage facilities include round metal tanks and metal or concrete silo-type structures. Most of these structures are gastight or they can be made adequately gastight for fumigation with a minimum of sealing. It would seem that when grain is being conveyed into storage would be the ideal time for applying a fumigant such as hydrogen phosphide or an insecticidal protective treatment such as malathion. Instead of ideal it is usually an impractical time to apply a treatment, especially to fumigate. Because the flow or supply of grain is irregular, it may require much of a harvest season before the storage facility is filled. Thus, much of the fumigant gases would be lost as grain is added and exposure of the grain handlers to the fumigant gas may be in question. The next best opportunity to properly treat the grain is by turning it from a tank or silo into another. This procedure requires the availability of an empty tank or silo, but a protective treatment or fumigant can be applied most efficiently and effectively. Because empty tanks or silos are not always available and it is expensive to turn the grain, attempts are sometimes made to fumigate the grain in place by probing or submerging the fumigant into the grain surface. Most of these fumigations are only partially effective.

Port Elevators: Essentially all port elevators or export facilities for grain are of the upright structure. They are best described as handling rather than as storage facilities. For this reason, any type of insect control remedy can cause an expensive delay in the movement of the grain. Because of the different varieties and grades of grain exported, even the largest port elevators can seldom store enough grain of one kind and grade for a complete shipment. Instead, enough grain is held to begin loading a ship, then a rather constant flow of grain is provided by railcars, trucks, and river barges to continue and complete the loading. In-coming grain found infested can be set aside and fumigated before it enters the elevators, but grain found infested after loading aboard ship is usually fumigated in-transit with one of the formulations of hydrogen phosphide. This fumigation procedure is described below.

Transportation Facilities: The time grain normally spends in the various transportation facilities - combines, trucks, railcars, containers, river barges and ocean vessels - is minimal; however, they can be important sources of insect infestation. Prolonged storage in such facilities as railcars, river barges and ocean vessels are unique situations and should be treated as storages rather than as transportation facilities. It will be only through well planned and implemented programs of hygiene, inspection and pesticide applications that we can be assured of reasonable control and prevent the spread of insect infestation into storage facilities.

An extensive program needs to be designed to educate the farmer on the value of cleaning old grain and grain refuse from combines, trucks and farm wagons. Trucks and wagons also should be sprayed with a residual insecticide following cleaning to control any insects that may be hiding in the cracks and crevices of the beds. These treatments of cleaning and spraying with a residual pesticide should be repeated with every transportation vehicle used in the market channel before loading it with grain. The use of grain protectants is also highly recommended at the first opportunity (i.e., binning or loading of the grain into a transportation facility). Repeated treatments of grain with a residual pesticide can result in residues that exceed the tolerance.

In the marketing channel when it becomes necessary for an exporter to marshall grain to meet a sales contract, it often starts grain moving as far back in the system as the farm. There usually is no opportunity for the grain merchant to assure himself that the grain purchased is free of insects or even if it has a protective treatment. There is rarely time in the marketing channel to treat grain that may be infested. The use of grain protectants requires exposure to the insects, usually adults, which are killed before they have an opportunity to start their next generation. The time involved here can be up to two or more generation times or several months before full or complete control is effected, if ever. Effective control is generally limited in the marketing channel to the use of a fumigant. However, control will be difficult to assure if treatment is made during the marshalling procedure. To be affective, the fumigant gas must be distributed throughout the grain mass and held for the required duration to kill the insects involved. Among the vehicles used to marshall grain, few are adequately constructed to retain fumigant gases. Those that may be adequately sealed or made gastight include hopper-type railcars and hopper-type trucks. Other types of railcars, trucks and even river barges either cannot be made gastight or it would be too expensive to make them gastight. Control will be most effective and efficacious if performed at the endpoint of the marshalling procedure where all the grain can be treated at one time. This is why the use of intransit shipboard fumigation has been so successful (Davis, 1982; Davis and Barrett, 1986). Researchers have tested several methods of intransit shipboard fumigation. The methods recommended by USDA/ARS are given in Chapter 2 of the FGIS Fumigation Handbook published September 28, 1987. Pages 2-3 through 2-5 (Appendix-D) explain the use procedures and limitations of each method. Hundreds of grain ships have been successfully fumigated annually by one or more of these methods. However, failures can occur if the applicator fails to apply the fumigant by the methods specified according to the depth of the grain.

Limitations on Current Technologies

Limitations on the use of residual insecticides and fumigants and their application and effectiveness may be seriously limited by the amount of time available, the space or volume to be treated, the economics or dollar value saved or gained by their use or legal restrictions on the use of various pesticides by local, state or federal governments. In the use of residual insecticides the effectiveness is dependent upon the grain and storage facility being properly treated. Similarly with fumigants, if there isn't sufficient time for the gas to reach all parts of the grain mass in the required quantity and for the required duration, the pest will survive.

When a control intervention is required or needed and one is applied which is ineffective this is lost money and often a lost reputation for the seller and the Nation. The economics in such a situation can be almost as one wishes to calculate them. If it is quality lost the value may be small or large, but this value is rarely calculated. The presence of insects of a certain number can result in a rejection of the grain or a discount of the price. This discount is usually applied as a loss to the seller or a cost to the buyer to treat the infested grain if he accepts it rather than a value of quality lost. If the problem of infestation is found in large quantities of grain such as might result in a complaint, condemnation or rejection of grain overseas, sufficient dollar loss in additional ship demurrage, legal action, investigations, division of cargoes, and loss of future sales can be a tremendous impact upon the seller and the Nation.

Interaction with Other Technologies

As related to insect infestations pest management to maintain or improve the quality of grain can be expressed as (1) prevention of insect infestation of the grain or (2) control of insect infestations if they occur. Then, the importance of any interaction of pest management with other technologies within the marketing and distribution system will depend on the approach taken to pest management.

Adulteration

The prevention of insect infestation should begin at the farm level with an extra effort to clean the grain and to remove most of the foreign materials. Then one of the protective treatments needs to be applied as the grain is conveyed into storage. Thus, one can visualize a great reduction in adulteration of the milled product from foreign materials and insect fragments. Without the pockets of high moisture sometimes caused by insects, a reduction in the formation of molds and the production of mycotoxins also may be experienced. Thus, the clean grain easily meets the grading requirements of the FGIS as well as the tolerances for the amount of foreign materials and numbers of insect fragments in milled products established by the Food and Drug Administration (FDA). However, there is another important factor to consider. As the grain moves from the farm through the various buyers to export or for domestic use, the identity of a particular treated lot is impractical to maintain. Thus, a treated lot may receive additional protective treatments as it moves through the marketing channels resulting in adulteration of either the grain or the milled product by the presence of excessive pesticide residue. Whether excessive pesticide residues result from one or more treatments, the grain is subject to impoundment or even destruction according to regulations of the FDA. Probably the greatest deterrent to implementing a preventative program is the hope by farmers and warehousemen that the grain will not become infested and any kind of a preventative treatment could be an unnecessary expense (or the infestation won't be detected by routine inspection by the buyer). Most grain handlers will agree that it is not a matter of, if the grain will become infested, but when an infestation will develop to the point that something must be done.

We can conclude that beyond routine cleaning and spraying empty storage facilities, very little preventative treatments are made on newly harvested grain (Barak and Harein, 1981; Storey et al., 1984). These treatments when made are mostly on wheat and rarely on corn or soybeans. Also, such protective treatments would occur most frequently in the southern-most grain producing and storage states where the climate is most favorable for insect activity.

In the absence of insect preventive treatments, control of infestations are taken into account on a case-by-case basis when they occur. If the grain is turned a protective treatment may be applied if it is believed needed. Most of the exposed adults may be killed, but all the immature insects inside the kernels of grain will not be killed until they emerge as adults. Even if the grain is fumigated, 100% kill of the insects may not be achieved. However, the population may be reduced to a nondetectable level and several generations may be required before the infestation becomes detectable or economically important again. In either case, numerous immature and even pre-emerged adult insects are inside individual kernels of grain. Many of these insects not removed by the pre-milling conditioning become fragmented during milling. The FDA has established defect action levels for insect fragments in milled products.

Inspection

Inspections are the basis of both good storage and the successful merchandising of quality grain. It is essential that farmers, elevator operators and others involved in storing grain have a management plan based on an effective inspection regime. This regime should involve close monitoring and the sampling of the grain for moisture, temperature, insects and molds . Grain samples should be taken at the time of first binning and subsequently at regular intervals during storage, perhaps even weekly in hot and humid ambient conditions. Only with an adequate and regular sampling regime can one expect to prevent such adverse conditions as moisture migration, heating ("hot spots"), the production of mycotoxins and insect infestation.

There currently is increased interest in the establishment of programs for managing on-farm stored grain (Raney et al., no date, prob. 1984; Gates and Gage, 1978; Harein et al. 1985). The USDA, Agricultural Research Service (ARS) has also initiated a research program on modelling insect populations in farm stored corn and wheat. The success of this modelling program will depend upon achieving methodology for securing adequate and reproducible samples. Similar population models have been developed in

Australia for insects in government wheat storages. While the value of modelling in the control of post harvest insect populations is questionable when the objective is nil insects, the Australians have found that models are useful as research tools in evaluating the success of control interventions (Personnel comm., D. E. Evans, 1987).

Inspections are also market enhancements and a part of quarantine activities. The grain inspections performed by the FGIS are essentially mandatory for all exported US grain and are often used within the continental US to expedite trade. The FGIS inspections, both for domestic and for export, are based on a fee schedule. The USDA, APHIS issues phytosanitary certificates at the request of the foreign buyers or as required by bilateral agreements with the foreign government importing the US grain.

The solution to the problem of grain quality must be addressed through the sample, the type of sample and its size, methodology used to secure the sample and its subsequent handling and evaluation. Recently there has been an increased dialogue within the grain trade and with USDA administrators and researchers regarding these factors and the resulting grade. This dialogue has resulted in some minor revisions in the US Grain Standards. On June 30, 1987, (FR 52 [125]:24414-24442), the term "weevily" was redesignated as "infested." The use of "infested" now denotes in wheat, rye and triticale that two or more live weevils, or one live weevil and one or more other live insects, or two or more other live insects injurious to stored grain, were found. In other grains it is the same, except it requires one live weevil and five or more other live insects or 10 other insects injurious to grain. This revision also added a limit of 32 insect-damaged kernels per 100 grams for the sample grade for wheat. It can not be said that these changes will effect an improvement in our export grain or reduce the number of complaints regarding infestation in our grain.

The significance of the number of visible insects or even their absence in a grain sample is not known. Birch (1984) has shown that for one species of weevil only 4.5% of the total population can be consiaered to be in the adult stage at any one time. There is need for research into how to take a representative sample, the ratio of visible insects to hidden infestation, importance of dead insects and the adverse effect of securing, delivering and handling the sample on any live insect that may be present. Knowledge of what our samples really mean would move us a quantum step towards the reduction of complaints involving all insect stages, live and dead, their fragments and parts in processed products, and the use of pest control interventions and their residues.

Outside Factors that Affect Performance of Intervention

Physical Factors

There are many physical factors that affect the performance of chemical interventions. Among these factors, temperature probably has the greatest ~~effect.~~ Usually, within well defined limits, an increase or decrease in temperature means a similar increase or decrease in the performance of an insecticide. This performance is apparently interrelated with a similar response of insects to temperature changes. The effect of temperature is most dramatic on the performance of fumigants, especially methyl bromide. For example, the concentration required to kill a given life stage of an insect decreases with an increase in temperature. Likewise, with a decrease in temperature, an increase in concentration is required.

High moisture content of grain increases sorption of fumigants such as methyl bromide (Lindgren et al. 1962); requires an increase in fumigant dosage; contributes to reduced seed germination; and accelerates breakdown of protective treatments such as malathion.

The effects of relative humidity are varied and minimal on the performance of most pesticides. However, hydrogen phosphide producing formulations require atmospheric moisture of at least 25% relative humidity to cause the chemical reaction that releases the gas.

Foreign material and dockage covers a wide variety of items that may be found in grain; however, grain dust and other "fines" have the greatest effect on the performance of insect control interventions. When a protective treatment is applied, grain dust may sorb much of the insecticide which reduces the effectiveness of the protection treatment. Likewise, when a fumigant is applied, the grain is said to be "tough" when it contains large amounts of dockage and more fumigant may need to be applied to overcome the toughness and achieve penetration. The dust content also inhibits penetration of the fumigant gases and causes channeling of the gases so that penetration is slow or not at all in certain parts of a grain mass.

Wind can be very detrimental to the performance of fumigants in particular. When fumigations are performed outside under gas proof tarpaulins, billowing of the tarpaulins caused by the wind can literally pump out the fumigant gas. Even when fumigations are performed inside, wind can cause important losses of gas (Winks, 1980). Under windy conditions, extra care is required in sealing any facility to be fumigated. Preferably, fumigation should be delayed until more favorable conditions prevail.

In most fumigations, especially of large masses of grain, some air movement within the grain is essential to achieve distribution of gas and biological efficacy. Forced air recirculation is generally required for methyl bromide and chloropicrin, but the natural mobility of hydrogen phosphide gas and the convection currents within a grain mass are relied on for its distribution. For many years, any means of forced recirculation of hydrogen phosphide was considered to be very dangerous because of its ignition or explosive potential. Though there have been some recent claims of successful recirculation of hydrogen phosphide, to date there is no proven method that is readily available for use. However, tests are in progress involving both USDA and USSR scientists and representatives of the grain and fumigation industries to assess the performance of a system for recirculating hydrogen phosphide in an in-transit shipboard fumigation of wheat (Davis, 1988). The success of this effort should provide the basis for the effective fumigation of other large quantities of stored grain.

Moving or turning grain can be used as an advantage when utilizing an insect control intervention. For example, when grain is moved from one storage site to another, it provides an opportunity to apply either a grain protectant such as malathion, or a fumigant such as hydrogen phosphide. Also, if malathion or hydrogen phosphide has been applied earlier, turning or moving the grain will tend to reduce the residues of the protectant and aid in the aeration of the fumigant. Thus coordination of grain movement with pest management interventions can compliment the control effected.

A good sanitation program is very important if the full value of any chemical control intervention is to be received. Dust, dirt, and other foreign materials frequently found in grain storage facilities will dilute and reduce the effectiveness of residual insecticide treatments. Dust, fines, and other dockage in grain reduces the performance of both protective treatments. A good sanitation program can actually reduce the need for pesticides to control insects, but the application of pesticides can not be used as a substitute for sanitation.

The gastightness of any structure or material used to cover a commodity or grain storage facility is of primary importance if a fumigation is to be successful. That is, the fumigant gas concentration must be maintained for the length of time required (Bond, 1984) to kill the least susceptible life stage of the insects involved. Thus, the fumigator must determine that a facility is adequately sealed to retain the fumigant for both efficacy and safety. The cause of most fumigation failures can be traced to inadequate gastightness of the storage facility. A sincere effort should be made to achieve gastightness rather than increase the fumigant dosage which is practiced sometimes especially with hydrogen phosphide. Higher dosages will not compensate for deficiencies in gastightness (Winks, 1980).

The competency of the applicator is a major factor in the performance of any pest management intervention. Only fully trained and qualified applicators should be entrusted with the application of pesticides such as grain protectants or fumigants.

An incompetent or inadequately trained applicator may apply too little or too much of a pesticide to the grain. In either case the grain is not protected or the grain may be contaminated with pesticide residues with high dosages. Inadequate training and experience is most likely to occur at the farm level where pesticide applications are often carried out by the farmers themselves.

Biological Factors

There are several biological factors that must be taken into account for the successful performance of any insect control intervention. Some of the important factors include (1) the species and life stage of the insects involved, (2) insect resistance to the insecticides available, (3) the kind and condition of the grain to be treated, and (4) presence of beneficial organisms such as parasites and predators.

Infestation of grain usually involves several species of insects. The susceptibility of insects to insecticide is quite variable among species, life stages, and even the ages of insects within a species.

Several species of grain infesting insects have developed a high level of resistance to malathion (Zettler, 1982), a moderate level of resistance to synergized pyrethrins (Zettler *et al*., 1973), and a few species have developed low levels of resistance to hydrogen phosphide (Champ and Dyte, 1976).

In theory, fumigant gases will permeate most readily through large kernel grain because of the large interkernel spaces; however, the presence of dust and fine particles (broken kernels) will tend to fill these spaces and slow the permeation. Also, the age of the grain or time in storage may retard permeation of fumigant gases due to compaction of the grain.

Financial Factors

The cost involved should not be a major deterrent to the timely and proper application of an insect control intervention. The cost of materials for fumigations or protective treatments is generally less than one cent per bushel of grain (Storey *et al*., 1984). Womack *et al*., (1984) reported that a complete control program that included a residual treatment of bins or warehouses plus a protective treatment or fumigation cost an average of 2 cents per bushel in Georgia. Barak and Harein (1981) conducted an extensive survey of losses associated with farm-stored corn and wheat in Minnesota. Also, Storey *et al*., (1984) included farm-stored corn and wheat in their study of pest management practices in 27 states. Among their many findings, both studies agreed that little action is taken by farmers to maintain the quality of grain during storage on the farm. Perhaps the farmers are convinced that the use of the insect control interventions will not assure the marketing of insect-free grain and discounts will still be invoked if live insects are found by the buyer.

Thus the expense of insect control may be unnecessary. Discounts for infested grain are invoked by most buyers throughout the marketing channels. The amount of such discounts are quite variable and may be based on the price paid per bushel and/or cost of subsequently fumigating and cleaning the grain. Harein *et al*. (1985) reported that discounts in Minnesota ranged as high as 17 cents per bushel of corn to 33 cents per bushel of wheat. In a survey of elevator managers across the mid-western states, Storey *et al*. (1984) reported that discounts ranged from 1 to 20 cents per bushel when live insects were found in the grain. Obviously, the incentives to initiate and maintain a high quality clean grain program at the farm level is either lacking or in question. Apparently, there is insufficient economic benefits for farmers to deliver insect-free grain to local markets or the insect control interventions in the hands of the farmers are inadequate to provide insect-free grain, or the farmers believe that the cost of insect control interventions can not be recovered when the grain is marketed.

Strengths and Weaknesses of Pesticide Intervention

The use of a pesticide should be considered as only a part of a pest management program. However, in today's marketing channels and for some time to come, chemical pesticides will likely play the most significant part in a pest management program aimed at maintaining and delivering quality grain. Therefore, it is important to understand both strengths and weaknesses of the available pesticide interventions so that a pesticide can be utilized for its strength against a specific problem.

Performance parameters

Some important strengths and weaknesses, respectively of the available pesticide interventions are as follows:

1. Pyrethrins:

    (strengths)

    a. Long history of safe use
    b. Fast acting with quick "knock down" of many species of insects
    c. Little or no insect resistance
    d. Repellent to insects

    (weaknesses)

    a. Expensive and not readily available
    b. Not as effective as desired (to kill insects)

2. Malathion:

    (strengths)

    a. Long history of safe use
    b. Effective against most grain infesting insects
    c. Economical and readily available

    (weaknesses)

    High levels of insect resistance in some locations

3. Pirimiphos-methyl:

(strengths)

a. Effects against malathion resistant insects

b. Relatively non-toxic to mammals

(weaknesses)

a. Relatively new and unknown on the market

b. Limited approval for use

4. Chlorpyrifos-methyl:

(strengths)

a. Effective against malathion resistant insects

b. Relatively non-toxic to mammals

c. Approved for use on wheat

(weaknesses)

a. Not approved for use on corn and soybeans except as a dust formulation

b. Relatively new and unknown on the market

5. *Bacillus thuringiensis*:

(strengths)

a. Effective against moth species

b. Non-toxic to mammals

(weaknesses)

a. Not effective against beetle species

b. Must be ingested to be effective

6. Inert dusts:

(strengths)

Economical

(weaknesses)

a. Generally not as effective as insecticides

b. Adds more dust to a dusty product

c. Abrasive to machinery

d. May involve fire and worker health risks

e. May reduce grade or test weight of grain

7. Methyl bromide:

(strengths)

a. Highly toxic to grain infesting insects

b. Fast acting for short-term fumigations

c. Non-flammable and non-corrosive to metals

(weaknesses)

a. Highly toxic to mammals

b. Odorless

c. Reacts with grain to form permanent residues, reduces seed germination

d. Requires forced recirculation for distribution

8. Hydrogen phosphide:

(strengths)

a. Highly volatile, good penetration without recirculation

b. Aerates completely without permanent residues

c. Odor provides good warning property

d. Formulations are simple to apply

(weaknesses)

a. Highly toxic to mammals

b. Flammable and explosive at high concentrations

c. Corrosive to copper, silver, gold (rare metals)

d. Highly toxic to insects but requires long term exposures (eg. 3 to 5 days or more)

9. Chloropicrin:

(strengths)

a. Very toxic to grain infecting insects and other pests

b. Non-flammable nor explosive

c. Does not react with grain to farm permanent residues

(weaknesses)

a. Highly toxic, iritating tear gas to mammals

b. Difficult to vaporize and aerate from grain

c. Requires forced recirculation for distribution

d. Corrosive to metals

Limitations and Constraints

There are several important factors that adversely affect the proper utilization of pesticide interventions. Very often the grain is moving so rapidly within the marketing channels that there is not enough time to apply a fumigant and it would be inappropriate to apply a protective treatment. Many times the storage facility may not be sufficiently gastight to be fumigated and storage time is too short to apply a long-term protection treatment. Also, the location and size of a storage facility can be important economic constraints to applying an insect control intervention. Unless there is a large quantity of grain or it is located convenient to the applicator, the cost of an insect control intervention may be prohibitive. A factor that must be considered is the cost of the insect control intervention verses any penalties that might be imposed for infested grain when it is sold.

Losses and Changes in Grain Quality

It is highly probable that any losses or changes in grain quality caused by any of the available interventions will be the result of misuse, such as the application of excessive amounts of a pesticide. For example, the protection treatments are intended to protect grains in storage for 9-12 months. During this period of storage, residues on the grain of a pesticide treatment such as malathion may degrade to only trace amounts. Thus applications of malathion that exceed the residue tolerance initially may not cause permanent damage.

Methyl bromide fumigations may cause permanent quality losses. Methyl bromide reacts with grain to deposit fixed residues of inorganic bromide. These residues are not especially harmful but they accumulate with dosage, duration of fumigation, and number of times fumigated. Excessive fumigations of grain with methyl bromide can result in tainting of the grain or the grain product.

Effect of Pesticide Intervention on Grain Quality

The use of pesticide interventions are intended to maintain the quality of grain as affected by insect infestations without causing any adverse effect on grain quality. The proper application of a pesticide intervention as a basic part of a pest management program can minimize damage by insects, thus maintaining the physical appearance of the grain as well as its basic nutritional value.

New and Emerging Technologies

Several new approaches to insect control or prevention in grain have been researched and brought to a usable point while others that have shown potential are still under study. Of the new technologies available for use, they have received little or no acceptance within the grain marketing channels because of costs or predetermined limitations of performance.

Modified Atmosphere

Modified atmosphere is a relatively new technology available for use against insect infestations in grain. Its basic performance parameters are similar to those of a fumigant as (1) the storage facility must be adequately gastight to retain the introduced (modified) atmosphere of either nitrogen or carbon dioxide and exclude oxygen, (2) the modified atmosphere must be maintained for several days, (3) a normal atmosphere must be restored before workers can safely enter the facility, and (4) there is no residual protection against reinfestation. The use of carbon dioxide appears to have the greatest potential as an alternative intervention for use as a grain fumigant (Davis and Jay, 1977: Jay and D'Orazio, 1984). Modified atmospheres are exempt from the requirements of tolerances.

Hermetic Storage

Hermetic storage of grain involves total sealing after a facility is completely filled to exclude air. Then, during long-term storage, the natural respiration of the grain and insects will deplete the oxygen and create an atmosphere lethal to the insects.

Irradiation

Much research has been completed that defines the parameters of irradiation required to kill or sterilize insects and to disinfect grain. Research to determine the amount of irradiation required to control grain infesting insects has been completed at USDA, Stored-Product Insects Research and Development Laboratory, Savannah, GA, in the late 1960's and early 1970's. The irradiation facility is now closed. Tilton and Brower (1987), who carried out most of those studies, are of the opinion that "irradiation should now be on a competitive basis with alternative methods of insect control." Although, most of their research was conducted with gamma radiation, Tilton and Brower and other researchers (Zakladnoi et al., 1981; Borsa, 1987) indicate that the electron acceleration method of irradiation is the most practical and may be the most economical method for use on grain. Irradiation of grain is approved for use in several countries including the US (Tilton and Brower, 1987). However, its use has been minimal probably because of the high initial cost of installation. According to Borsa (1987) the capital cost of an accelerator installation capable of treating 1,000 tons of grain per hour would be in the four million dollar range. By operating the unit two shifts per day, 6 days per week, the maximum annual throughput would be 5 million tons. With this throughput and all foreseeable operating costs, he calculates that treatment can be as low as 23 cents per ton. He points out that the cost per ton will increase as the throughput decreases.

There may be as many as 25 industrial organizations that would be willing and very capable of constructing a grain irradiation facility (Tilton, 1987).

Temperature

At temperatures of 15°C (60°F) or lower, most insect activity ceases. That is, there is little or no feeding or reproduction by grain infesting insects, but many of them will survive long periods of exposure at these temperatures. At temperatures near freezing (0°C or 32°F) it requires 10 days or more to actually kill some species of grain infesting insects (Mullen and Arbogast, 1984). This time will be extended based on the density of the infested product, the amount stored, and the cooling capacity of the freezer unit. Obviously, the technology is available and is used to maintain the quality of certain high value agricultural products. However, it would be economically impractical to freeze large masses of stored grain by mechanical refrigeration. In areas where climatic conditions provide natural cold temperatures, the aeration systems of storage facilities are used to reduce the temperature of stored grain to achieve insect control.

High temperatures can be used to kill the life stages of grain infesting insects. As with cold temperatures and even fumigants, the heat must permeate the grain so that the temperature of both the grain and the insects is increased. Kirkpatrick and Tilton (1973) found that a 4-day exposure to 43.3+1°C (110±1.8°F) killed more than 99.9% of two important species of grain infesting insects. They found that by increasing the temperature of thin layers of infested grain to 65.5±1.5°C (149±2.7°F) by infrared radiation, grain infesting insects were killed instantaneously (Kirkpatrick and Tilton, 1972). In a comparative study of microwave and infrared radiation to heat grain Kirkpatrick *et al*. (1972) concluded that either method could be used to disinfest thin layers of grain, such as on a grain conveying system but that infrared was favored for safety and economic reasons.

Fluidized bed heating with hot air can be an effective method of utilizing high temperatures to disinfest grain (Vardell and Tilton, 1981; Evans _et_ _al_., 1984). By forcing heated air upward through a bed/layer of grain at a rate sufficient to elevate and separate individual kernels, the grain becomes mobile or fluid. By this method the grain temperature is quickly increased to that of the heated air. In general, researchers agree that a grain temperature of about 70°C. (158°F.) is required for a rapid disinfestation procedure. In their studies with a pilot plant, Evans _et_ _al_. (1984) found that by operating at 150 tons per hour at a grain temperature of 25°C, the cost of operation ranged from 45 cents per ton by using natural gas to 63 cents per ton by using LP gas. Also, they estimated that installation of a facility with a 500-ton per hour throughput of grain would cost about one million dollars.

Biological Control Agents

Of the many biological agents investigated by researchers, few have proven to be useful as insect control agents in stored grain. The bacterium, _Bacillus_ _thuringiensis_ is effective against grain infesting moths and is labeled for use as a grain protectant. McGaughey (1985) has shown that bioagents such as _B_. _thuringiensis_ is not without problems when his laboratory tests showed that the Indianmeal moth could develop resistance.

Sex pheromones have been synthesized for many species of grain infesting insects. These pheromones have proven useful in trapping insects to indicate the need for control measures.

An insect growth regulator, methoprene, has been developed and labeled as a protective treatment for farmers stock peanuts but not for grain. Research into these and other biorational compounds would be very beneficial.

The parasitic wasp, Bracon hebetor, and the predaceous bug, Xylocoris flavipes are found often in natural populations of stored-product insects. The predaceous bug, in particular, has shown potential for controlling insects in farmers stock peanuts (Press et al., 1975) and for use against residual populations of insects in empty warehouses (LeCato et al., 1977). However, the augmentation of parasites and predators into a facility used to store food probably would be interpreted by FDA as adulteration of the commodities stored in the facility.

Inert Dusts

Much research has been conducted with a wide variety of inert dusts that show varying degrees of effectiveness as grain protectants. In general the protection rendered was less than desired and less than could be obtained with approved pesticides. The addition of dust to grain only magnifies a dust problem that is already in need of serious attention. It would seem that there is little merit for the development of an inert dust as a grain protectant.

Traps

Several types of insect traps have proven effective for indicating the presence of insect infestations of grain but none can be considered to be control agents. Light traps and sex pheromone baited traps are effective in trapping adult insects that fly. A probe-type trap (Loschiavo and Atkinson, 1967) that is inserted into the grain is most effective in trapping immature and non-flying insects (Barak and Harein, 1982). However, considerable research is still needed to relate trap catches to the degree of infestation.

Potential for New Interventions

Hydrogen phosphide has been in use in the United States as a grain fumigant for at least 20 years. With the exception of modified and oxygen depleted atmospheres (CO_2 and N_2) it is probably the last compound approved for use as a grain fumigant. Hundreds of new compounds have been evaluated for their fumigant potential, but none have proven useful as grain fumigants.

The greatest potential for use of new residual-type pesticides may be in expanding the approved usage of the relatively new insecticides pirimiphos-methyl and chlorpyrifos-methyl. Both compounds appear promising for replacing malathion as grain protectants. Both are effective against malathion resistant insects, but are less than totally effective against the lesser grain borer, a major pest of stored grain. In Australia mixtures of bioresmethrin, a synthetic pyrethroid, with chlorpyrifos-methyl has been shown to be effective. The use of insecticide mixtures has not received proper attention because regulations require safety data on all components as well as the mixture.

Impact of New and Emerging Technologies on the Current State-of-the-Art

Only two of the new and emerging technologies mentioned, modified atmospheres and irradiation, seem likely to affect the present state-of-the-art as insect control interventions in grain. However, both of these technologies have inherent limitations that will hinder if not permanently delay their implementation. In the case of modified atmospheres, whether nitrogen (N_2) or carbon dioxide (CO_2) is applied or an exothermic burner and condenser is used to create a low oxygen (O_2) atmosphere, the logistics of providing the large quantities of N_2 and CO_2 or the initial cost and maintenance of the burner system will hinder the implementation of this intervention. Also, for this intervention to be used effectively and efficiently, the facility being treated must be well sealed, a factor so often neglected for fumigation especially with hydrogen phosphide.

In the case of irradiation, the initial cost of installation is probably the greatest hindrance to implementing this intervention. Another cost factor not common to other insect control interventions is the level of training and maintenance of technicians to operate an irradiation facility. Also an irradiation facility not mobile will require varying degrees of transportation of grain to be treated.

Changes in Research Needs and Approaches

Some research needs that should enhance the quality of grain includes the following:

A. Develop grain storage, handling, and transportation facilities that are compatible with insect control technologies. It has long been recognized that old grain and grain residues left in these facilities from one use to the next usually harbors insects that "infest" new grain placed in them. The basic construction of some of the facilities make it difficult if not impossible to remove all of the old grain and residues by the most diligent cleaning effort.

B. Determine fumigant/treatment methodology that will achieve quarantine-type treatment of large masses of grain. The basic technology for achieving this type of treatment is available provided certain conditions can be met. If the grain can be turned into a well sealed tank or silo, hydrogen phosphide can be added to the grain stream. This procedure offers assurance of a successful fumigation. Likewise, methyl bromide could be used effectively if a properly installed recirculation system were available. These conditions can not always be met either physically or economically where large masses of grain are involved. This problem is often demonstrated at export terminals when large quantities of infested grain are inadvertently placed aboard a ship. Research has shown that hydrogen phosphide is the fumigant of choice but the most effective procedure developed often falls short of a quarantine-type fumigation that may be required by the receiving country.

C. Implement a "clean-grain" program with incentive awards. Throughout much of the 1950's emphasis was placed on the conduct of a clean grain program by the appropriate state (Gates and Gage, 1978. Appendix-A) and federal agencies and the grain industry in general. According to a publication by the Federal Extension Service (1955 Appendix-B), the program was basically a strong educational effort emphasized by a threat of economic loss if the grain was "found to contain filth or contamination from insects, birds, or rodents". A clean grain program based on the promise of economic benefits rather than losses should be more receptive to the grain trade, and endure longer than the original program that is essentially unknown in the marketing channels today.

Impact of Costs Associated with Changes in Research Needs and Approaches

Monies invested in pest intervention research and its application methodology can have a very significant and impressive impact. Some examples of the impact would be:

- an increase in the number and quantity of export sales;
- an increase in quality in both domestic and export sales with a corresponding decrease in complaints and their accompanying discounts;
- increased prices for the US farmer and US agribusiness entities; and
- a reduction in US surpluses and government subsidies.

Presently much technology is available for application even though some provide less than the desired efficacy. Nevertheless, efforts need to be put forward to promote this technology and find new safer and more effective application methodologies to minimize the reported hazards of presently available chemical interventions. Some available pesticides may need to be severely restricted to assure a safe environment but rarely is cancellation and market withdrawal seen as necessary. Allowing inexperienced teenage drivers on the highway has never prompted a consideration of returning to the horse and buggy. Still highway accidents that kill hundreds of times more people per year than pesticides have ever harmed are accepted as a force *majour*.

There is a very real need for pest management programs for post harvest grain storaging, transporting, handling and processing. Presently our limited knowledge mandates that before such programs can be perfected there is a demand that we increase our information on insect biology and ecology, insect detection and sampling techniques, improved application methodologies for chemical pesticides and fumigants, cause of pesticide residues and the perfection of novel non chemical pest control interventions.

FUMIGATION AND OTHER INSECT MANAGEMENT INTERVENTIONS

Summary

In addition to quantitative losses of grain, insects cause other losses of grain quality such as nutritional value, viability of seed and even aesthetic values. The proper use of a fumigant is the only available and entirely satisfactory method of ridding grain of an infestation. Other types of insect control pesticides are available and, if timely applied will reduce the need for fumigants, but not to the extent that fumigants are no longer needed.

The use of residual-type insecticide applied to the surfaces of storage facilities and admixed with the grain placed in storage is effective in protecting the grain from becoming infested. The use of residual-type insecticide with emphasis on hygienic procedures was the basis of a Clean Grain Program that proved successful during the 1950's.

Spillage, sweepings, and other residues of grain in and around grain storage facilities provide an ideal habitat for grain infesting insects even when the facilities are empty. Thus, thorough cleaning is the first and most important step toward preventing insect infestation of newly harvested grain.

After cleaning, the surfaces of grain storage facilities such as walls and floors that will come in contact with the grain should be sprayed with an approved residual type insecticide such as malathion, chlorpyrifos-methyl, synergized pyrethrins, or methoxychlor. Then, as the new grain is conveyed into storage, an approved insecticide should be admixed with the grain as a protective treatment. When properly applied, a grain protectant will prevent or minimize additional damage by an existing infestation and protect clean uninfested grain from becoming infested.

Fumigation is the highly specialized art of applying some of the most toxic and unique pesticides. Only three compounds, methyl bromide, hydrogen phosphide, and chloropicrin are presently available as grain fumigants. However, the application of high levels of carbon dioxide or nitrogen or exclusion of oxygen is available as a type of fumigation.

Because of the conditions under which fumigation is needed or desired, it is seldom practical or economical to attempt 100% kill of insects. Thus, the approach taken is to kill enough of the insects to minimize losses and to make the grain acceptable to the buyer. This type of fumigation should be minimize or avoided entirely. Insects not killed are exposed to sublethal dosages of the fumigant which is the basis for insects developing resistance. Insect resistance to any of our registered fumigants means a major loss in our last line-of-defense.

None of the insect control interventions can be considered a cure-all. However, each has some useful characteristics that can be intergrated into good insect management programs for stored grains.

Several new insect control interventions for use in grain have been developed or are still being researched but none have shown potential as a grain fumigant. Of the new insect control interventions available, modified or oxygen depleted atmospheres and irradiation have the greatest potential for immediate or near future use.

Some research needs that should enhance the quality of grain include the following:

1. Develop grain storage, handling, and transportation facilities that are compatable with insect control technologies.
2. Determine fumigant/treatment methodology that will achieve quarantine-type treatment of large masses of grain.
3. Implement a Clean Grain Program based on economic benefits.

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Glossary

Admixture: The application of an insecticide to grain as a dust or spray so that good coverage (admixing) is achieved to protect the grain against insect infestation. (see protectant).

Aeration: The removal of fumigant gases either by cross ventilation or by forced air movement using fans. Forces air movement (aeration) as used to cool stored grain.

CXT (Concentration times time): The product of the average fumigant concentration in milligrams per liter multiplied by the time in hours required to kill the target organism at a given temperature.

Defect Action Level: The amount of foreign material such as the number of insect fragments in a food product at which action must be taken to remove from the market.

Emulsifiable Concentrate: A formulation of insecticide containing a high percentage of active ingredients that emulsifies in water which dilutes the active ingredients to the desired percentage for application.

Halide Lamp:	A copper ring heated by a propane flame that caused the flame to change color in the presence of a gaseous halide such as methyl bromide.
Knock Down:	Insects so affected by an insecticide that they are unable to walk or fly.
Label:	A legal document attached to each pesticide container that provides instructions for safe use.
Labeling:	Literature provided by the manufacturer of an insecticide that provides detailed information on benefits and limitations of their insecticidal product.
LD_{50} (Lethal Dose):	The insecticide dosage required to kill 50% of the exposed insects.
Mites:	Mites are similar to but not true insects. Some species infest and damage grain.
Moisture Migration:	The upward movement of water vapors in warm grain to colder grain resulting in condensation usually on or near the grain surface.
Mg/kg (Milligrams per kilogram):	The milligrams of an insecticide per kilogram of body weight required to kill on a tabulated % of the animals exposed.

Phytosanitary Certificate:

Certifies that the grain is free of quarantined pests and pests injurious to grain and it complies with phytosanitary regulations of the importing country.

Protectant: An insecticide used to apply to or admixed with grain to protect it from insect infestation.

Restricted Use Pesticide:

An insecticide restricted to the purchase and application only by a certified applicator.

Space Spray: An insecticidal aerosol or fine mist applied into the free space above the grain or other stored commodities.

Synergized: The efficacy of the insecticide pyrethrins can be increased (synergized) by the addition of the synergist, piperonyl butoxide which blocks the insect's detoxifying mechanism.

Tainting: Adverse flavor and/or aroma caused by excessive fumigation with methyl bromide.

Turning (grain):

The movement of grain from one storage tank/silo to another.

TWA (Time Weighted Average):

The allowable exposure of workers to chemical vapors (fumigant gases) based on the amount accumulated during an 8-hour period.

Weevil: Insects (beetles only) that live and develop from egg to adult inside individual kernels of grain.

APPENDIX-A

APPENDIX-B

APPENDIX-C

APPENDIX-D

Background Paper No. 8

Alternative Grain Transportation and Distribution Technologies and Their Impact on Grain Quality

C. Phillip Baumel
Iowa State University

March 1989

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Enhancing the Quality of U.S. Grain for International Trade." The views expressed are those of the author(s) and not necessarily those of OTA.

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Introduction

Previous research indicates that changes in grain quality occurring in the movement from origin points to final users are primarily the result of deterioration during loading and unloading, handling within grain elevators, and from moisture, temperature and time characteristics. Hill, Paulsen, Shore et al. (1985), found that loading corn in an ocean vessel added an average of 1.5 percentage points of BCFM (broken corn and foreign material). Unloading the grain from the ocean vessel into barges at importing ports added about three percentage points to the BCFM content. They also found that segregation of BCFM occurs during the loading and unloading of the vessel. Hill, Paulsen, Mounts et al. (1981), found that the BCFM in 1,000-ton sublots unloaded from 11 vessels ranged from 3.4 to 18.9 percent, while the vessel averages ranged from 5.0 to 10.5 percent.

Several studies have documented corn breakage resulting from free-fall drops in grain elevators. Foster and Holman (1973) found that corn, which had been dropped 30.5 meters, had breakage ranging from 7.1 to 12.5 percent at moistures of 15.2 and 12.6 percent, respectively. Chung, Chung and Converse (1973) measured mechanical damage to corn during pneumatic conveying. A high conveying air velocity caused the greatest damage, with damage more pronounced in dry corn.

Paulsen, Hill and Shore (1986) found that test weight and moisture were unaffected by loading procedures, but that the change in damage during transport was in response to biological factors associated with time, moisture and temperature. Most of the change in temperature during transport occurred within one meter of the surface walls and floor of the ship hold.

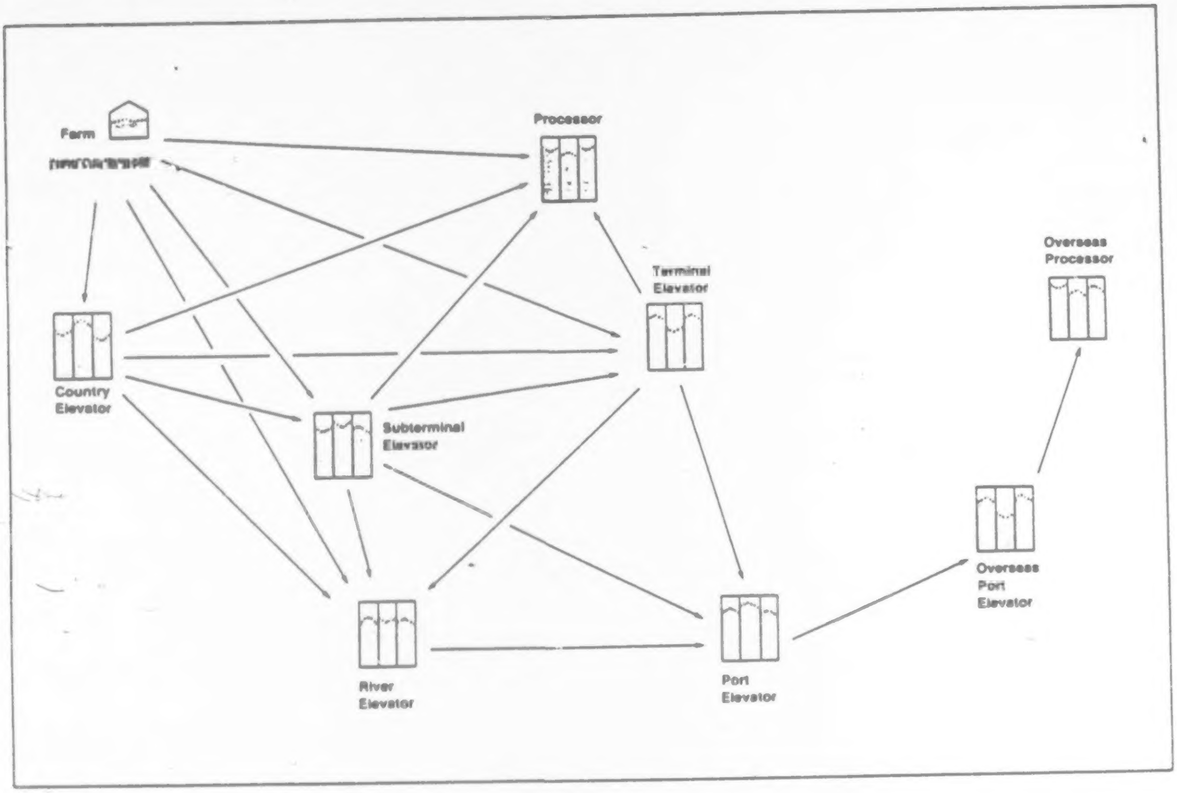
DeHoff, Stroshine, Tuite et. al. (1984) sampled 15 barges of shelled corn at barge loading elevators and at export elevators in the New Orleans area where the barges were unloaded. In most cases, corn quality remained high during shipment. However, in some barges, incomplete blending and/or improper loading procedures resulted in levels of fine material exceeding 12 percent and moisture levels exceeding 17 percent. The combination of excessive fine material and moisture resulted in mold infection in some samples.

These studies suggest that grain quality deteriorates as the grain moves through the transportation and distribution system. The objective of this paper is to describe the current grain transportation and distribution system technologies and to suggest strategies and needed research to minimize grain quality deterioration as it moves from origin locations to final users.

Current Transportation and Distribution Technologies

Figure 1 illustrates the principal routes by which most of the grain moves from farms to domestic processors and importing users. Grain may be transported from farms by trucks or farm-tractor wagons to country elevators, subterminal elevators, river elevators, inland terminal elevators or directly to domestic end

Figure 1. General flow of grain from the farm through the system.


Farm
Processor
Terminal Elevator
Overseas Processor
Country Elevator
Subterminal Elevator
Overseas Port Elevator
River Elevator
Port Elevator

Source: U.S. Department of Agriculture, "The Physical Distribution System for Grain," Office of Transportation, Agriculture Information Bulletin Number 457, Washington, D.C., October 1983.

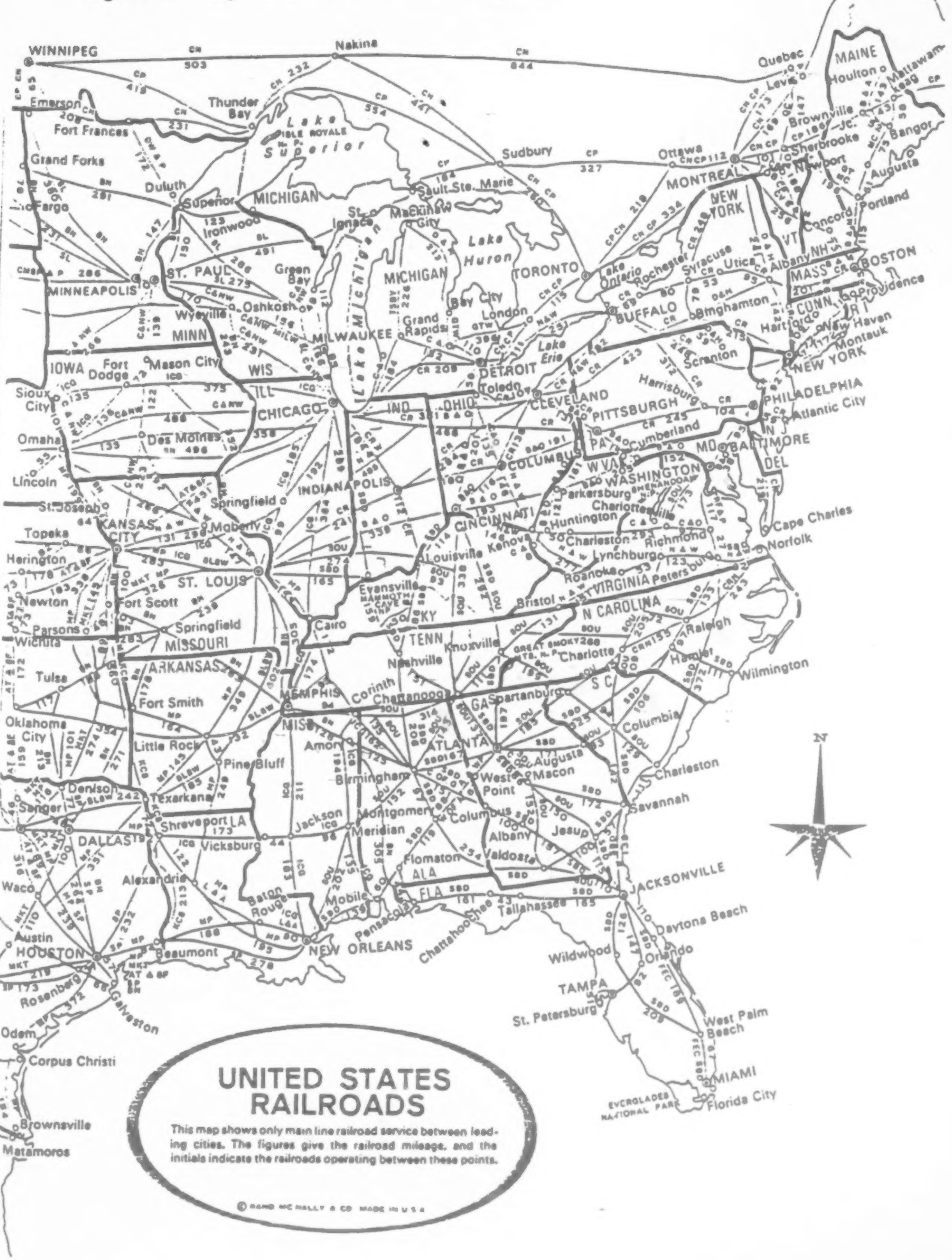
users, which could be processors or livestock feed lots. Domestic end users may obtain grain directly from farms by trucks or from country elevators, subterminals or terminal elevators by trucks or railroads. Grain can be shipped directly by rail, truck-barge or rail-barge from country elevators, subterminals or inland terminal elevators to export elevators located at ports on the East Coast, Gulf of Mexico, Great Lakes or West Coast for transshipment into ocean vessels for transport overseas (see figures 2 and 3 for possible rail and barge routes). Some farmers and elevators located close to these export ports transport grain directly to export elevators by truck. In addition, some grain is shipped in unit grain trains directly from subterminals or inland terminal elevators directly to Mexico. A small amount of wheat and corn moves directly into Canada by truck. Thus, the major carriers of grain are rail, truck, barge and ocean vessels.

It is virtually impossible to obtain an accurate measurement of the share of grain hauled by each mode of transport because:

1. No agency collects data on shipments of grain by truck.
2. Some grain is hauled by several modes while moving from originating country elevators to final users. Thus, there is some double counting in the reported quantities hauled by railroads and barges.

Table 1 shows the reported quantities of grain moved by railroads and barges and the modal shares of the combined total. The railroad share ranged from a high of 80.3 percent in 1974 to a low of 66 percent in 1982. The barge share tended to rise or fall

Figure 2. Map of the U.S. railroad system.


UNITED STATES RAILROADS
This map shows only main line railroad service between leading cities. The figures give the railroad mileage, and the initials indicate the railroads operating between these points.
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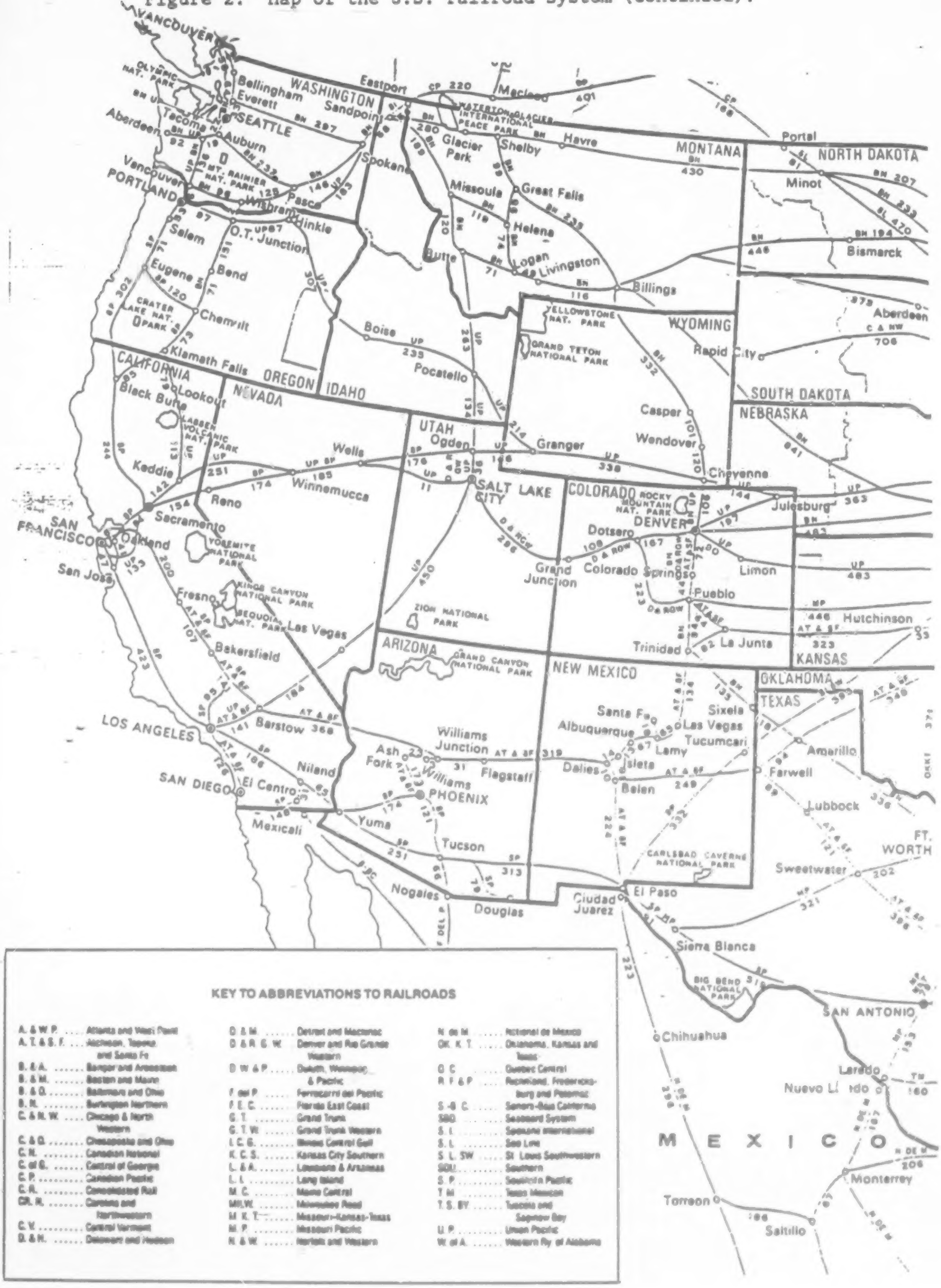
WINNIPEG
Nakina
Quebec
MAINE
Thunder Bay
Lake Superior
Sudbury
Ottawa
MONTREAL
Duluth
Superior
MICHIGAN
Lake Huron
TORONTO
NEW YORK
BOSTON
MINNEAPOLIS
ST. PAUL
Green Bay
MILWAUKEE
DETROIT
BUFFALO
Lake Erie
CLEVELAND
PITTSBURGH
PHILADELPHIA
NEW YORK
IOWA
CHICAGO
Des Moines
Omaha
Lincoln
INDIANAPOLIS
COLUMBUS
BALTIMORE
WASHINGTON
KANSAS CITY
ST. LOUIS
CINCINNATI
Louisville
Richmond
Norfolk
MISSOURI
Springfield
Nashville
Knoxville
N CAROLINA
Charlotte
Raleigh
Wilmington
ARKANSAS
MEMPHIS
Chattanooga
ATLANTA
Columbia
Charleston
Oklahoma City
Little Rock
Birmingham
Savannah
DALLAS
Shreveport
Jackson
Montgomery
JACKSONVILLE
HOUSTON
NEW ORLEANS
Mobile
Tallahassee
Daytona Beach
Orlando
TAMPA
St. Petersburg
West Palm Beach
MIAMI
Florida City
Everglades National Park
Galveston
Corpus Christi
Brownsville
Matamoros
N

Figure 2. Map of the U.S. railroad system (continued).


VANCOUVER
WASHINGTON
Bellingham
Everett
SEATTLE
Tacoma
Aberdeen
Auburn
Spokane
Sandpoint
Eastport
Vancouver
PORTLAND
Wishram
Pasco
Hinkle
Salem
O.T. Junction
Eugene
Bend
Chemult
Klamath Falls
OREGON
IDAHO
MONTANA
Glacier Park
Shelby
Havre
Missoula
Great Falls
Helena
Butte
Logan
Livingston
Billings
NORTH DAKOTA
Portal
Minot
Bismarck
Aberdeen
Rapid City
SOUTH DAKOTA
NEBRASKA
WYOMING
Casper
Wendover
Cheyenne
Granger
Boise
Pocatello
CALIFORNIA
Lookout
Black Butte
Keddie
NEVADA
Wells
Winnemucca
Reno
Sacramento
SAN FRANCISCO
Oakland
San Jose
Fresno
Bakersfield
Las Vegas
Barstow
LOS ANGELES
SAN DIEGO
El Centro
Niland
Mexicali
UTAH
Ogden
SALT LAKE CITY
COLORADO
DENVER
Julesburg
Dotsero
Grand Junction
Colorado Springs
Limon
Pueblo
Trinidad
La Junta
Hutchinson
KANSAS
ARIZONA
NEW MEXICO
Williams Junction
Ash Fork
Williams
Flagstaff
PHOENIX
Yuma
Tucson
Nogales
Douglas
Santa Fe
Albuquerque
Las Vegas
Lamy
Dalies
Isleta
Belen
Tucumcari
Sixela
OKLAHOMA
TEXAS
Amarillo
Farwell
Lubbock
Sweetwater
FT. WORTH
El Paso
Ciudad Juarez
Sierra Blanca
SAN ANTONIO
Laredo
Nuevo Laredo
Chihuahua
MEXICO
Monterrey
Torreon
Saltillo

KEY TO ABBREVIATIONS TO RAILROADS

A. & W. P.	Atlanta and West Point
A. T. & S. F.	Atchison, Topeka and Santa Fe
B. & A.	Bangor and Aroostook
B. & M.	Boston and Maine
B. & O.	Baltimore and Ohio
B. N.	Burlington Northern
C. & N. W.	Chicago & North Western
C. & O.	Chesapeake and Ohio
C. N.	Canadian National
C. of G.	Central of Georgia
C. P.	Canadian Pacific
C. R.	Consolidated Rail
CR. N.	Carolina and Northwestern
C. V.	Central Vermont
D. & H.	Delaware and Hudson
D. & M.	Detroit and Mackinac
D. & R. G. W.	Denver and Rio Grande Western
D. W. & P.	Duluth, Winnipeg & Pacific
F. del P.	Ferrocarril del Pacific
F. E. C.	Florida East Coast
G. T.	Grand Trunk
G. T. W.	Grand Trunk Western
I. C. G.	Illinois Central Gulf
K. C. S.	Kansas City Southern
L. & A.	Louisiana & Arkansas
L. I.	Long Island
M. C.	Maine Central
MILW.	Milwaukee Road
M. K. T.	Missouri-Kansas-Texas
M. P.	Missouri Pacific
N. & W.	Norfolk and Western
N. de M.	Nacional de Mexico
OK. K. T.	Oklahoma, Kansas and Texas
Q. C.	Quebec Central
R. F. & P.	Richmond, Fredericksburg and Potomac
S.-B. C.	Sonora-Baja California
SBD.	Seaboard System
S. I.	Spokane International
S. L.	Soo Line
S. L. SW.	St. Louis Southwestern
SOU.	Southern
S. P.	Southern Pacific
T. M.	Texas Mexican
T. S. BY.	Tuscola and Saginaw Bay
U. P.	Union Pacific
W. of A.	Western Ry. of Alabama

Figure 3. Inland waterway system.

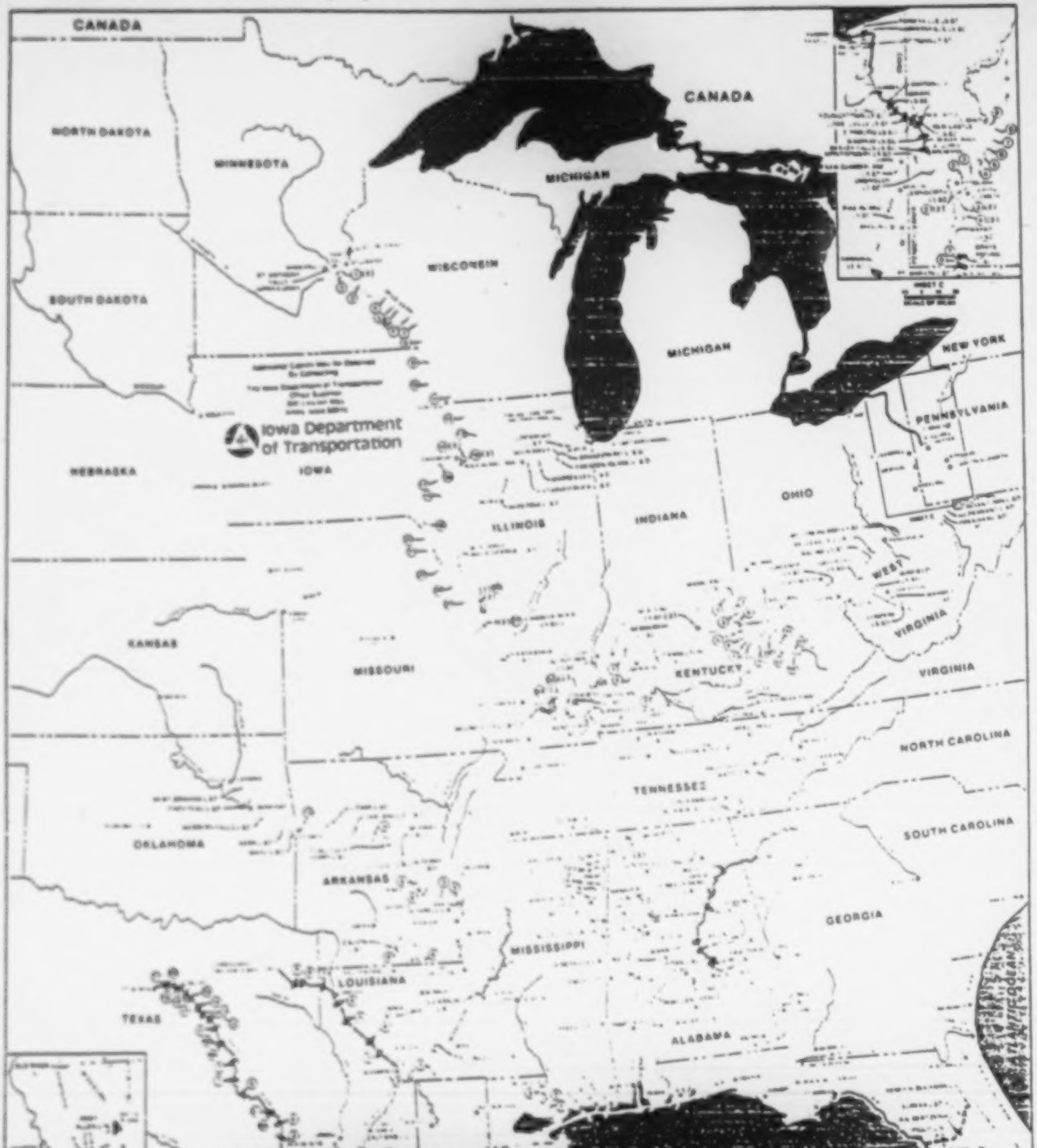

CANADA
CANADA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
WISCONSIN
MICHIGAN
MICHIGAN
NEW YORK
PENNSYLVANIA
Iowa Department of Transportation
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
WEST VIRGINIA
KANSAS
MISSOURI
KENTUCKY
VIRGINIA
NORTH CAROLINA
TENNESSEE
OKLAHOMA
ARKANSAS
SOUTH CAROLINA
GEORGIA
MISSISSIPPI
LOUISIANA
TEXAS
ALABAMA
ATLANTIC OCEAN
FLORIDA
MEXICO
MISSISSIPPI RIVER AND TRIBUTARIES
INLAND WATERWAYS SYSTEM
LEGEND
EXISTING PRINCIPAL WATERWAY
WATERWAY UNDER CONSTRUCTION
AUTHORIZED WATERWAY
OTHER WATERWAY
EXISTING LOCK OR LOCKS
LOCK OR LOCKS UNDER CONSTRUCTION
AUTHORIZED LOCK OR LOCKS
LOCK NAMES
NUMBER OF MULTIPLE LOCKS
SCALE OF MILES

Table 1. Quantity of grain hauled by railroads and barges in billions of bushels, 1974-1985.

Year	Quantity moved by		Percent moved By	
	Railroads	Barges	Railroads	Barges
1974	4.21	1.03	80.3	19.7
1975	4.06	1.20	77.3	22.7
1976	4.10	1.61	71.8	28.2
1977	3.91	1.52	72.0	28.0
1978	4.12	1.63	71.7	28.3
1979	4.41	1.62	73.1	26.9
1980	5.00	1.91	72.4	27.6
1981	4.38	1.99	68.8	31.2
1982	4.22	2.18	66.0	34.0
1983	4.72	2.11	69.1	30.9
1984	4.81	1.97	70.9	29.1
1985	3.99	1.67	70.5	29.5

Source: Association of American Railroads, "The Grain Book 1986," Information and Public Affairs Department, Washington, D.C., 1987.

as exports increased or decreased, primarily because almost all grain moving by barge is destined for export ports.

The railroad share of grain moved to export ports declined from 62 percent in 1974-75 to 38 percent in 1983-84 (Association of American Railroads, 1987). Since trucks haul only a small amount of wheat and corn directly to export ports, the barge share of grain moved increased from about 37 percent in 1974-75 to about 60 percent in 1983-84. Except for the relatively small amount of grain moving into Mexico by unit trains, ocean vessels transport almost all grain exported from the United States.

Rail Transport

Since the late 1830s, railroads have been the major carrier of grains. The 1830s technology of single boxcar shipments remained the dominant grain transport technology until the late 1960s. The boxcar technology required the grain to be dropped from the top of a grain elevator through flexible pipes that directed the flow of grain into either end of the car through the center car doors. Later, some grain elevators used high speed grain throwers to blow the grain into each end of the boxcar. In either method, the impact of the grain against the end of the boxcar tended to create broken grain and foreign material.

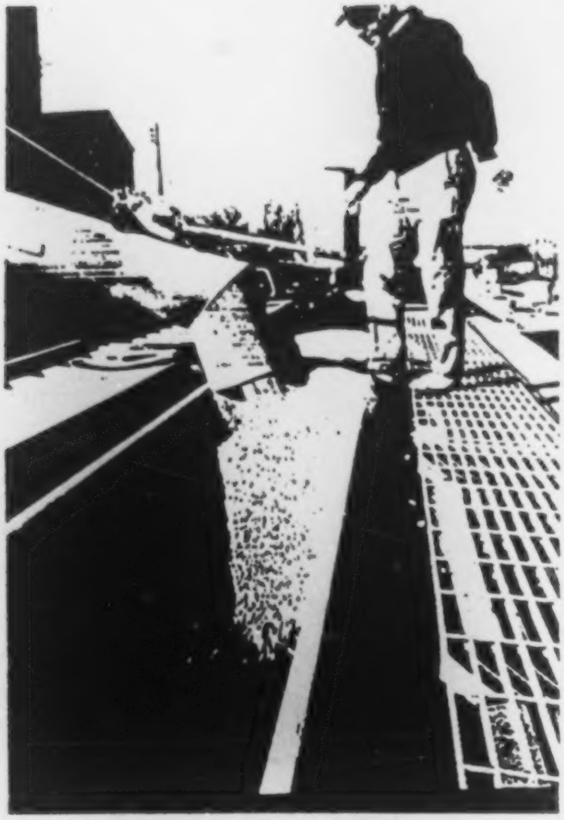
Boxcars had no floor unloading devices. Therefore, unloading the grain was accomplished with an electric shovel which was a drag pulled by a cable attached to an electric motor in the elevator. The drag pushed the grain to and out of the center doors into an unloading pit. Later, unloading devices were designed to lift and tip the car in either direction so the grain would flow out the center doors. This technology was costly and damaging to the grain.

Most box cars had an inside wood wall liner. Frequently, the inside liners were damaged and any bulk materials, including grain, carried by the car could fall into the gap between the inside and outside walls. This trapped material was, for all practical purposes, impossible to remove. It was a ready source of insect infestation, which was damaging to all grains, especially wheat.

The advent of the jumbo covered hopper car in the mid-1960s greatly reduced the stress on grain quality from loading and unloading rail cars. Covered hopper rail cars have full length top hatchways for relatively gentle grain loading (see figure 4). They also have bottom hopper slides for very gentle gravity unloading and they are relatively easy to clean prior to loading. Moreover, the covered hopper cars are tight and essentially leak-proof. Therefore, the grain stays dry and the tightness makes the covered hopper car a good vehicle in which to fumigate wheat with plostoxin pellets. By 1985, 99.6 percent of all grain transported by rail moved in covered hopper cars (Association of American Railroads, 1987).

Prior to the mid-1960s, almost all grain transported by rail moved under single-car "transit rates." The transit privilege allows grain to be shipped to a transit location where it is

Figure 4. Loading a covered hopper rail car.



unloaded for storage or processing and later reloaded and shipped to a final destination. The transit cost is usually lower than the inbound rate to the transit location plus the outbound rate from the transit location to the final destination. In the mid-1960s, railroad companies began publishing low-cost multiple-car and unit-train rates from country elevators directly to processors and export ports. A unit train is a group of loaded rail cars shipped from one origin to one destination under one bill of lading. Most unit trains consist of 50 or more loaded rail cars. In some cases, unit trains consist of blocks of cars loaded at two or more origin facilities located close together. Unit trains eliminate the need to stop at numerous country elevators to pick up grain cars for switching into a train. In addition, the turn-around time from the country elevator to the destination to the country elevator is much faster for unit trains than for single-car shipments. Thus, unit trains result in reduced switching costs and lower fuel and crew costs and enabled the railroads to haul more grain with their existing car fleets. A portion of these cost savings are passed on to shippers in the form of lower rates which, in turn, enabled the railroads to be more competitive for grain traffic. By the mid-1970s, multiple-car and unit-train shipments from originating elevators directly to end users and export ports had become the standard method of transporting corn and soybeans by rail. A 1985 survey of Iowa country elevators indicated that only 3.9 percent of rail grain shipments by the Iowa sample was in single-car shipments, while 14.6 percent was in multiple-car shipments and

81.5 percent was in unit trains (Interstate Commerce Commission, Appendix III, 1987). This shift to large direct rail shipments not only reduced the cost of grain transportation, but also reduced damage to the grain by eliminating the unloading into transit elevators and reloading into rail cars for shipment to processors or export ports.

While the transit privilege has been virtually nonexistent in the corn-soybean system since the mid-1970s, it still performs a major function in the wheat distribution system. Grain industry sources estimate that approximately half of all wheat transported by rail from Kansas, Oklahoma and Texas moves under transit rates. The main reasons for the continued use of the transit privilege for wheat are:

1. A large percentage of the grain storage capacity in the hard red winter wheat-producing regions is located at inland terminal transit locations like Enid, Oklahoma, and Hutchinson, Kansas. In contrast, most of the grain storage capacity in the corn belt states is at country elevator locations.
2. Aggregating large quantities of wheat at inland terminals permits the blending of wheat to meet export grade and quality specifications. Only a small number of modern local wheat elevators are capable of blending and grading wheat to meet these specifications on a regular basis.

While the wheat belt continues to use single-car transit shipments into terminal elevators and multiple-car and unit-train shipments to final destinations, the widespread use of direct multiple-car and unit-train rail shipments of corn and soybeans reduces quality deterioration by eliminating the extra handlings at transit locations.

Barge Transport

Most of the grain moving by barge originates on the Mississippi River system which includes the Illinois and Ohio rivers. These rivers became navigable when a system of locks and dams, constructed in the 1930s, made the entire river system navigable at nine-foot drafts. The Missouri River is usually navigable at nine-foot drafts; this level of navigation was made possible by straightening the river which increased the speed of the current and made the river self-dredging. However, at low water times, the Corps of Engineers may release insufficient water from reservoirs in the Great Northwest to enable barges on the Missouri River to be loaded at full capacity.

All grain moving by barge must be transported by truck or rail to barge loading elevators, where the grain is typically lifted by bucket belts into elevator storage bins and then later elevated again to the top of the elevator for gravity flow down pipes into barges that hold about 1,500 tons each.

A barge tow, consisting of 12 to 30 barges and pushed by a towboat, then begins a 15-25 day trip to the New Orleans area for unloading into an export elevator. During most harvest seasons, barges are used as storage space in the New Orleans area which can result in substantial delays in unloading some barges. Other causes of unloading delays include adverse river conditions, delays in switching newly loaded barges into barge tows and delays at locks and dams.

Typically, barges are unloaded by lowering a marine leg, a vertical belt with large attached buckets, into the barge to scoop up the grain and lift it into the export elevator storage bins. When a barge is nearly unloaded, a small crawler tractor with a front-end blade is lowered into the barge to push the remaining grain to the marine leg to complete the unloading.

The major export ports served by barges are the Mississippi River ports in the New Orleans area. In addition, the Columbia-Snake River serves the Pacific Northwest ports of Portland and Astoria, Oregon, and Vancouver, Kaloma and Longview, Washington.

The major advantages of the barge mode are the large carrying capacity of the barge tows and the relatively low rates charged to transport grain to deep water Mississippi River export ports. Table 2 shows the range of rail and rail-barge rates for grain shipments from west central Iowa to New Orleans. Rail rates decline as the size of the shipment increases on both direct to New Orleans and to Mississippi River destinations. Barge rates fluctuate with the supply and demand for barges. During the 1980s, barge rates generally fluctuated between 100 and 200 percent of the Merchants Exchange of St. Louis trading benchmarks. Even with barge rates at 200 percent of tariff, the combined rail-barge rates are sharply lower than rates on rail direct to New Orleans. Thus, the barge mode has become the dominant mode of transporting export

Table 2. Comparison of rail and rail-barge rates from Jefferson, Iowa, to New Orleans in dollars per ton (X-084A rail rates).

Mode	Size of shipment	Rail direct to New Orleans	Rail to Clinton, Iowa, barge to to New Orleans
Rail	25-car	$25.40	$7.20
	50-car	23.60	6.60
	75-car	21.40	6.00
Barge at 100% of tariff			5.32
Barge at 200% of tariff			10.64

Source: CBOT Master Rail Rate Book, Chicago Board of Trade, Transportation Department, Chicago, Illinois, and Merchants Exchange of St. Louis, Barge trading benchmarks, St. Louis, Missouri.

grain to deepwater ports on the Mississippi River. The rail-barge rate advantage increases with origins located closer to the Mississippi River.

However, there are grain quality disadvantages of barges including:

a. extra handlings to load and unload the barge,

b. slow speeds (four to eight miles per hour downstream) which require up to three weeks of transit time plus additional time waiting to be unloaded,

c. high humidity and high temperatures in the New Orleans area if the grain is not uniformly loaded and dry.

It should also be recognized that rail shipments may incur substantial waiting time to be unloaded at some export elevators, particularly during peak shipment periods.

Ocean Transport

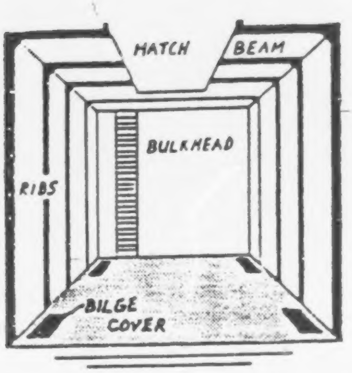
In the 1960s, the P.L. 480 government program dominated grain exports. A substantial portion of these grain exports were simple FOB--free on board--sales, in small 10,000- to 15,000-ton vessels. Many of the small 10,000- to 15,000-ton vessels were multipurpose vessels with several decks and small holds. Loading these small, so-called "'tween decker" vessels often caused damage to the grain because of stairways and other obstacles to the free flow of grain. To provide cargo and vessel stability and to obtain full utilization of the vessel capacity, there was a need to "trim" or blow the grain into the corners of the small holds. Trimming the vessels also damaged the grain when it was forced up into the corners of each hold. These vessels were also difficult to unload for the same reasons. Some of the newer, 20,000- to 30,000-ton automobile ships, which use grain as a back haul, must also be trimmed.

During the 1970s, world prosperity, combined with the low value of the dollar and the general desire of foreign nations to improve diets, increased cash export sales substantially above the P.L. 480 volume. Importers and exporters shifted a high percentage of their ocean shipments to larger 50,000-ton or more Panamax ships to gain lower per ton shipping costs. In recent years, increasing amounts of grain are exported via OBO (oil bulk ore) vessels of up to 100,000 tons.

Some grain also moves in tanker vessels which are used primarily to transport oil. Configuration of tanker vessels can be very damaging to grain quality (see figure 5 for configurations of bulk dry cargo, 'tween decker and tanker vessels). Grain must be loaded through a small opening in the middle of each hold and most of it bounces off a ladder permanently affixed to the opening. In addition, some of the grain bounces off baffles attached within the holds. Finally, unloading these vessels causes additional damage to the grain because of the small openings, the ladders and baffles which require high speed pneumatic unloaders with many elbows in the unloading tubes.

The increase in cash purchases during the 1970s affected the terms of sale as well as the size of shipments. A large portion of the grain purchased by foreign buyers was delivered on a Cargo,

Figure 5. Configuation of bulk dry cargo, 'tween decker and tanker vessels.

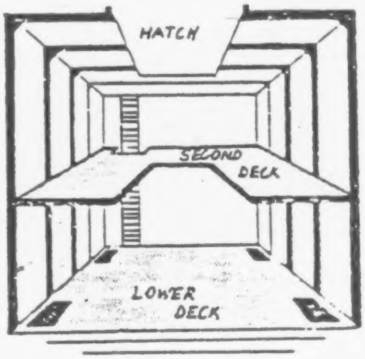

HATCH
BEAM
BULKHEAD
RIBS
BILGE
COVER

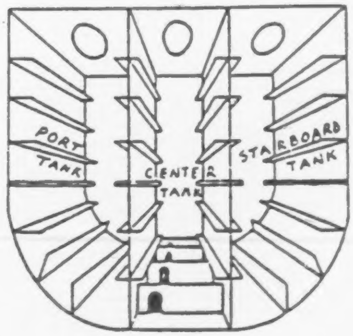
BULK DRY CARGO

Bulk dry cargo ships are widely used to transport grain. The holds of these ships are normally box-like in shape.

'TWEEN DECKER

'Tween deckers are much like bulk dry cargo ships. The shape of the holds is similar except that 'tween deckers have additional decks between the main deck, secend deck, and lower deck.


HATCH
SECOND
DECK
LOWER
DECK


PORT
TANK
CENTER
TANK
STARBOARD
TANK

TANKER

Tankers are primarily used to transport oil in bulk. They are sometimes used however to transport grain. Tanker holds come in a variety of configurations; this is just one example.

Insurance and Freight (CIF) basis or Cargo and Freight (C and F) basis. A gradual shift from FOB to CIF during the decade required that the additional risk of ocean freight be assumed by the exporter.

The decade also saw the rise of "optional origin" trading. Under this type of sale, buyers agreed to accept the commodity from any origin in the world at the seller's option once the grade, price and other terms of trade had been established. This option allowed exporters to take advantage of changes in freight and foreign exchange rates and market swings that occurred between the booking and the execution of the sale. Some of these savings were passed on to foreign buyers in terms of lower prices in exchange for accepting the optional origin contracts.

The larger 50,000-ton Panamax dry bulk vessels are relatively easy to load and unload because of their large open holds. However, these vessels are not free of grain quality problems in loading and unloading. While most of these vessels are "self trimming" on the sides of the holds, most vessels must be trimmed on the fore and aft ends of each hold with a "spoon" device that diverts the grain into the unfilled spaces.

Most of the Panamax vessels have roll-top hatches which expose much or all of the hold for ease of loading. However, if the loading spout remains in the same location throughout the loading process, the fine material tends to accumulate in the center of the cone in the hold and the whole kernels tend to roll to the sides. If the moisture content is not uniform in the shipment, the accumulation of fine material creates an opportunity for mold and spoilage.

The segregation of fine material within each hold of a vessel can create quality complaints at importing ports. The buyer of the imported grain (usually a for-profit merchant or government buying agency) is rarely the end user. In most instances the entire cargo is divided up after unloading and delivered to the end users within the receiving country or, in some cases, is subdivided at a receiving terminal and transshipped into other means of conveyance for delivery to the receiving country. Inspection and weighing certificates issued by the Federal Grain Inspection Service in the United States cover the average quality and specific quantity of the entire cargo and do not represent the quality of any individual piece that may be unloaded.

When bulk grain is loaded, the quality is not uniform within the holds due to the natural segregation of fine material. When it is discharged and broken down and delivered as separate units, the entire cargo is rarely reblended. This results in some end users receiving grain that is higher in quality than was reported on the loading certificate while others receive grain lower in quality. This has caused some end users to lodge quality complaints. The problem of breaking down entire cargoes and comparing individual pieces to the average quality is further compounded by the Federal Grain Inspection Service's policy of issuing separate certificates, when requested, for quality and quantity to cover each individual portion of the entire cargo. In these cases, separate certificates are issued for each individual portion. Each certificate states the average quality for the entire cargo and only distinguishes the breakdown by weight of each portion.

In order to resolve the problems associated with distributing an entire cargo to many receivers, some countries have begun to specify that each individual portion be loaded and separately inspected and weighed during loading. In these instances, a layer of burlap or plastic cloth and plywood is placed between the individual portions in the ship holds.

The first sublot is loaded in a normal fashion. The top of the first sublot is leveled and two alternative types of covers are placed over the leveled top. The first type is a complete separation of the two sublots of grain. It consists of a complete layer of plywood sheets and a full cover of burlap or plastic cloth. The total cost of one separation in a 7,000-ton hold of a 50,000-ton Panamax vessel is approximately $4,000. The cost per ton varies with the amount of grain to be identity preserved. These costs do not include additional unloading costs.

The second type of separation of simply placing about 20 sheets of plywood on the top of the first sublot. The plywood serves as a guideline to the separation. While this method is substantially less costly, it is also much less effective in actually separating the two sublots.

External Forces Affecting the Quality of Grain During Transport

Four interrelated variables, all external to the mode of transportation, which can determine the amount of grain spoilage in transit are distance transported, time in transit, ambient temperatures and the level and distribution of the grain moisture content. The key variable is the level and distribution of moisture content. When the level of moisture content is low and evenly distributed throughout the cargo, the effect of distance, time in transit and temperature is negated. If, however, the moisture content is high or unevenly distributed, distance, time in transit and temperature combine to create spoilage during transit. The DeHoff, Stroshine, Tuite et. al. (1984) samples were taken during the spring and summer. The likelihood of greater moisture variation and warm temperatures in the New Orleans area at harvest time can create severe quality deterioration if there are substantial delays in unloading the barges.

Control of Vessel Loading

For a majority of grain export sales, the longshoring or loading of the grain from the elevator spout into ocean vessels is arranged by the buyer, buyer's agent or ship company. In these cases, the export elevator has little or no control over the loading of the vessel. Export grain firm representatives indicate that, at some ports, five persons are used to load the ships when three could handle the job adequately. More important, however, longshoremen often do not move the spout around the hold to get an even distribution of the grain, thereby causing segregation of the fine material and the whole kernels or berries. Moreover, the flow of grain is sometimes directed to the side of the hold where the impact results in more broken kernels, particularly for corn and soybeans. Wheat berries, particularly hard wheats, are more durable than corn and soybeans. While abrasion does result in the loss of some wheat bran particles, inappropriate loading procedures are a greater problem for corn and soybeans than for wheat.

In some cases, exporting firms have formed their own longshoring firms so that they can control loading procedures. However, exporting firms indicate that, in a majority of the sales during the 1980s, the buyer hires the longshoring and there is little concern by the buyer about the impact of loading procedures on grain quality. Some grain firm executives believe that some stevedoring companies are now aware of the impact of loading practices on grain quality and that the loading problem is less severe than in the past.

Grain Merchandising System

Many train, barge and ocean vessel grain cargoes are sold several times before they reach the final destination. Grain industry executives indicate that some cargoes are sold several times while enroute to their final destination. In effect, these buyers and sellers are trading paper rather than grain. A uniform set of grade standards provides more trading and profit opportunities than a set of standards with many characteristics.

The paper trading of cargoes is a major reason why some grain trade officials are opposed to developing alternative grain standards which better describe end use value. Thus, if alternative grain standards are recommended as a method of improving grain quality, the grain trade will need to be shown that profits from improved quality exceed the profits from multiple in-route trading.

The current grading technology used by most grain firms does not describe the end use value of grain. New technologies are under development which will promptly and accurately describe end use values at interior and export locations. There will be grain trade opposition to developing alternative grain standards until these new technologies are perfected and adopted by the grain trade (Hurburgh).

Export Grain Embargoes

Two grain embargoes were imposed on export grain sales during the past decade. These embargoes can result in low grain quality if there is insufficient storage space to unload grain that is moving to export ports in rail cars and barges. Unloading delays can result in spoilage if the ambient temperatures are high and the grain is not uniformly dry.

Alternative Grain Transportation Systems

The economic function of the grain transportation and distribution system is to transport the grain from the origin elevator to the final destination at minimum cost subject to maintaining a specified level of grain quality. Figure 1 indicates that a large number of alternative routes can be used in moving grain through the system. Assuming a minimum of two handlings--one in and one out--at each elevator location, it is possible for grain to be handled up to 14 times in moving from the first elevator to a final user in an importing country. This does not include the number of times grain is handled on the producing farms or within elevators for blending or drying purposes. Thus, there is an interrelationship between the transportation and distribution system that affects grain quality. Changes in either the transportation or distribution system require changes in the other system and it is necessary to focus on both systems simultaneously to improve grain quality.

The U.S. grain transportation and distribution system is probably the most efficient system in any grain exporting country in the world. Much of this efficiency was achieved during the 1970s when the demand for export grain placed enormous stress on the U.S. grain transportation and distribution system. The decade was characterized by chronic rail car shortages, a deteriorating railroad system, bankrupt railroads, rapidly rising barge rates and congestion at U.S. export elevators in attempting to receive and load out enough grain to meet sales commitments. This stress eventually resulted in:

1. very large investments to increase the size of the covered hopper rail car and barge fleets,

2. a shift to a low cost, highly efficient, unit-train system with large subterminal elevators constructed to load unit trains,
3. a beginning of the rebuilding of the locks and dams on the Mississippi River,
4. large investments in rebuilding the railroad system accompanied by abandonment of a large portion of the light density branch rail lines,
5. consolidation of the bankrupt rail line tracks into the systems of the remaining railroad companies,
6. and finally, construction of several very modern export elevators, particularly on the Mississippi River and on the West Coast. Several of these new export elevators with conveyor belt systems are designed for gentle handlings of grain.

These investments have resulted in a high speed, low cost grain transportation and distribution system. Industry observers believe that the U.S. is now capable of exporting up to eight billion bushels of grain per year, whereas in the mid- and late 1970s the system was under great stress to export 3.5 to 5.0 billion bushels. Table 3 shows a comparison of 1984 system transport costs from the U.S. corn belt and Cruz Alta, Brazil to Japan and the EEC. The U.S. had about a $10 transport cost advantage over Brazil to Japan and about an $8 cost advantage over Brazil to the EEC. While the inland transport costs were approximately equal in the U.S. and Brazil, the inland distances

Table 3. Estimated transportation costs for soybean shipments from selected U.S. and Brazil origins to Yokohoma, Japan, and Rotterdam, the Netherlands, in 30,000 dwt ocean vessels, in dollars per tonne, April 1984.

		Mode				
Origin	Destination	Unit-train	Truck	Barge	Ocean	Total
Jordan, IA	Yokohoma	$5.80	--	$9.17	$14.74	$29.71
Clarence, IA	Yokohoma	--	$4.04	9.17	14.74	27.95
Paxton, IL	Yokohoma	11.57	--	--	14.74	26.31
Cruz Alta, Brazil	Yokohoma	13.77	--	--	23.49	37.26
Jordan, IA	Rotterdam	5.80	--	9.17	9.43	24.40
Clarence, IA	Rotterdam	--	4.04	9.17	9.43	22.64
Paxton, IL	Rotterdam	11.57	--	--	9.43	21.00
Cruz Alta, Brazil	Rotterdam	13.77	--	--	15.58	29.35

Source: T. Lee, C. P. Baumel and R. Acton, "The Impacts of Transportation Rates on World Soybean Competition," Proceedings o World Soybean Research Conference III, Richard Sibles, editor, Westview Press, Boulder, Colorado, 1985.

the grain is hauled from the cited origins are about 4.5 times longer in the U.S. than in Brazil. The U.S. ocean rates and distances to Japan were approximately half those from Brazil to Japan.

The U.S. grain transportation and distribution system has several disadvantages including:

1. Major U.S. grain-producing regions are located long distances--up to 2,000 to 3,000 miles--from major export ports (Lee, Baumel and Acton, 1985).
2. The high speed, low cost efficiency of the U.S. grain distribution system does not readily accommodate special grain quality needs. While these needs can be accommodated by slowing the speed of belt and bucket conveyors, by installing cleaning equipment, by eliminating unneeded handlings and by preserving the identity of the grain, most of these actions increase costs.
3. The grain distribution system, as currently organized, has large investments in duplicate and out-of-location grain handling and storage facilities, which tends to increase the number of handlings:
    a. The abandonment of a large number of branch rail lines during the 1970s left many country elevators without rail service. Most of these elevators are still in operation. A substantial portion of the grain

received at these elevators is trucked to subterminal elevators which receive, store and later load the grain into unit trains. At least two handlings could be avoided if the grain would be delivered directly from the farm to the subterminals. In effect, the elevators on abandoned lines recreate a transit type system for corn and soybeans which causes grain damage with each extra handling. While subterminals do not have sufficient storage capacity to handle all the grain, handling damage would be reduced if elevatrors without rail service would serve truck markets rather than transferring grain to subterminals. Because of the hardness of the berry, wheat is less affected by the extra handling in the transit system.

b. As shown in table 4, almost 60 percent of the U.S. export elevator storage capacity is located at the Great Lakes and Atlantic ports. Yet, in 1986, less than 12 percent of the U.S. corn and wheat exports moved through these ports. If grade standards were revised to require a multitude of grades reflecting end-use value, a large increase in storage capacity would likely be required to separate the various grades at export port elevators. The large storage-export imbalance at Gulf of Mexico and Pacific export elevators suggests that additional storage capacity would be required at these elevators.

Table 4. Percentage of U.S. export elevator storage capacity and corn and wheat exports by port range, 1986.

Port range	Number of elevators	Percent of total export elevator storage capacity	Percent of 1986 corn and wheat exports
Atlantic	11	10.8	5.5
Great Lakes	30	47.2	6.1
Gulf of Mexico	23	28.5	64.3
Pacific	15	13.4	24.1

Source: U.S. Department of Agriculture, "Grain Transportation Situation," Office of Transportation, Washington, D.C., various issues.

U.S. Department of Agriculture, Unpublished list of export elevators, Federal Grain Inspection Service, Washington, D.C.

Emerging Technologies

Only two new transportation technologies could help preserve grain quality during transportation; these are capsule pipelines and long distance belts. Air transport would be prohibitively costly.

The pipeline technology would transport the grain in capsules propelled by air pressure. Long distance belts would gently carry the grain from selected origins to major using locations such as a processor or barge loading facility. Recent studies on the economic feasibility of capsule pipelines indicate that distance and quantity carried are the major determinants of the economic feasibility of pipelines. Koo found that capsule pipelines are less costly than the variable costs of unit trains on shipments less than 300 miles and quantities in the range of 66 million bushels per year (Koo, 1983). The short distances mean that shipments from the corn-soybean-wheat belt would be limited to river destinations for barge shipment to export ports. The large volume requirements are unlikely to be available to any inland shipping elevator unless the grain is trucked or railed to the pipeline loading elevator. This would increase costs and number of handlings. Once the grain is loaded on a truck or unit train, usually the cheapest method of transporting the grain is to haul it directly to the destination. Another possibility for pipelines or belts is to transfer grain very short distances from large elevators to nearby export elevators to ocean vessels unable to reach the export elevator because of shallow water ports. These technologies are likely to be more suited for coal transportation where there are very large supplies and demands at single locations (i.e., coal mines and steam-generated electric utility plants). The ubiquitousness of grain supplies effectively rules out the use of these technologies for the movement of grain from country elevators.

Modification of Existing Technologies

Identity Preserved Grain

The basic concept of identity preservation is that individual grain shipments are not comingled with other grain shipments. Thus, the grain shipped by the country elevator is the exact grain that the end user would receive. Current FGIS rules permit exemptions and waivers from the requirement that all grain exported from the United States be officially inspected and weighed (U.S. Department of Agriculture, November, 1983). Thus, it is possible to export special qualities of grain that are different from current official U.S. grain standards. These exemptions and waivers should be useful for identity preserved grain. Among the possible methods of shipping identity preserved grain are:

- Unit Trains Directly From Country Elevators or Subterminals to Mexico. Grain shipped directly from country elevators or subterminals to Mexico is not handled or blended after leaving the shipping elevator until it is received by the Mexican user. Thus, the Mexican buyer receives exactly the same quality of grain that is shipped by the country elevator or subterminal by avoiding the poor handling practices at Mexican ports. The major problems with this method are:

a. the difficulty in getting the U.S. rail cars back from Mexico,

b. this method works only for exports to Mexico. It does not work for the bulk of U.S. grain exports which must be transported by ocean vessels,

c. many Mexican end users cannot use a full unit train load and the grain must be divided into sublots for truck delivery to end users. Thus, the unit train method does not solve the problem of damage during handling within Mexico,

d. grain grading and inspection costs if performed at non-terminal locations.

- Containers. Since the mid-1970s, most of the manufactured imports into the United States have been shipped in 20- and 40-foot containers. A large share of these containers return empty to Japan, Korea and Taiwan. Special high quality grain, such as seeds and soybeans for human consumption, have been exported in these containers from the U.S. for years. However, little or no commercial grade grains have been shipped in containers. Grain shipped in containers from country elevators would not be handled until it was unloaded by the end user. Thus, containers could substantially reduce the number of broken kernels in corn and fine material and would ensure that grain could be shipped to meet individual end user quality needs. Cost, however, is a major problem with the container option.

The cost of shipping containerized grain is substantially higher than any of the current bulk shipping technologies. The author and an Iowa subterminal operator, in attempting to ship commercial grade corn in containers, found that the rates on containerized grain shipments are in excess of double the cheapest bulk grain technology. However, it may be possible to negotiate substantially lower contract rates with railroad and container ship companies that are closer to current bulk rates. If this is possible, buyers would need to pay some premium for the improved quality and to cover the additional cost of the containerization.

- Identity Preservation Within Ship Holds. A method currently used to preserve the identity of commercial grain is to place a layer of burlap or plastic cloth and plywood between sublots of grain within a ship hold.

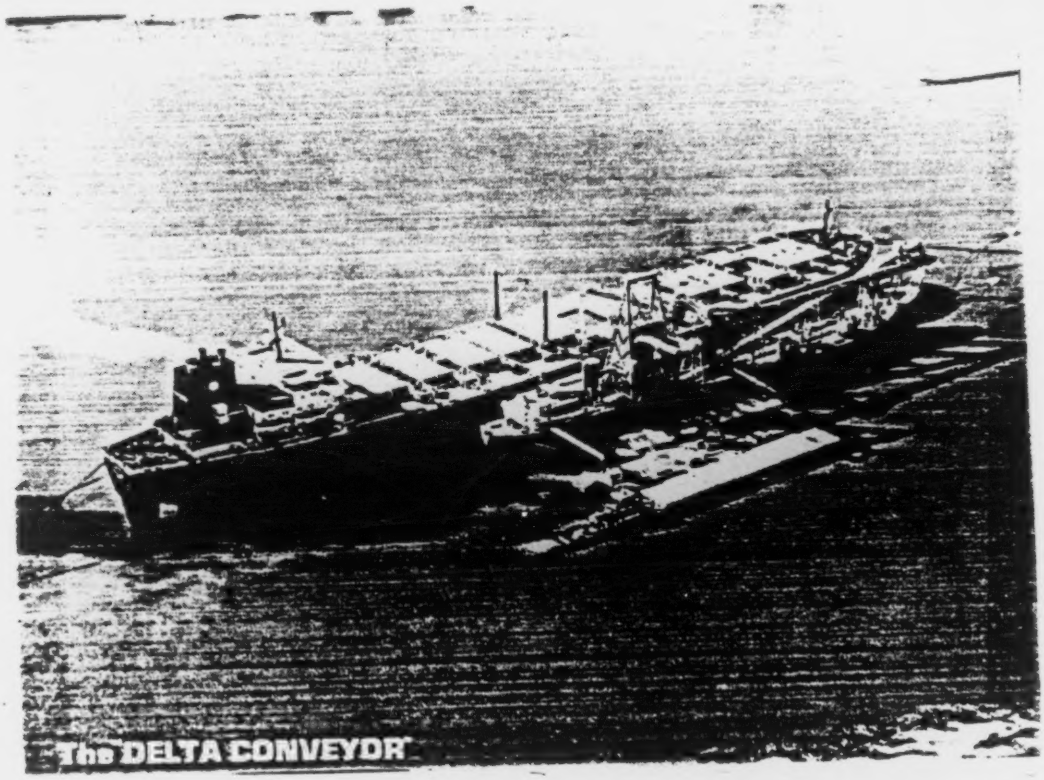
- Minivessels. A third method of shipping identity preserved grain is to load it in the small holds of minivessels and ocean going barges. These ships, with 2,000- to 7,500-ton capacities can be self-propelled or towed. Rates for these vessels are too costly for long distance shipping of commercial grain and tend to be used for shipments to Caribbean Sea destinations. However, the minivessel rates to these destinations are still very high, ranging from up to $25 per ton from the New Orleans area to Jamaica and

Puerto Rico. In comparison, grain rates in 50,000-ton vessels for shipments from New Orleans to Amsterdam are about $8 to $10 per ton. Thus, the high cost of minivessels limits their use to nearby import destinations in the Caribbean Sea and South America. However, they are sometimes used for shipments of P.L. 480 grain shipments to East African ports. On P.L. 480 shipments, the very large differences between U.S. flag vessel and a foreign flag bulk carrier vessel rates are subsidized by the U.S.D.A.

Direct Transfer

One method of reducing the number of grain handlings is to transfer the grain directly from one mode of transport to another mode of transport without unloading the grain into an elevator. For rail cars, direct transfer is made by simply unloading the grain from a rail car into an unloading pit and transferring the grain by a conveyor belt or auger directly into a barge or ocean vessel. Direct transfer from barges can be accomplished by the conventional unloading method of a marine leg at an export elevator and transferring the grain by a conveyor belt to the ocean vessel; a second method is by using a floating conveyor to transfer the grain from a barge to an ocean vessel (see figure 6). Each direct transfer usually avoids a minimum of two within-elevator handlings. Eliminating these within-elevator handlings is significant if the direct transfer avoids long free falls into elevator bins. However, there are logistical problems in a direct transfer operation.

Figure 6. A floating conveyor transferring grain from a barge to an ocean vessel.


The DELTA CONVEYOR

First, a sufficient quantity of grain must arrive on time to fill the receiving vessel in a timely manner. This is not likely to be a problem in directly transferring grain from trucks or railroad cars to barges, since each barge holds only about 1,500 tons. However, loading a 50,000-ton ocean vessel could create significant logistics problems. For example, the rail grain receiving capacity of most export elevators is not fast enough to load a 50,000-ton ship without incurring demurrage problems on either the railroad cars or the ocean vessels. The same problem arises in loading directly from barges to ocean vessels. If the ocean vessel arrives late, there will likely be demurrage charges on the barges at a rate of approximately $100 to $250 per day per barge, depending on the length of time from arrival until unloading. If some barges arrive late, the exporter will incur substantial demurrage charges on the ocean vessel.

Second, there are approximately 12 "floating conveyors" located in the New Orleans area that are specifically designed for direct transfer of commodities from barges to ocean vessels. However, the cost of direct transfer by "floating conveyors" is higher than through export elevators. Current elevator charges are $2.50 to $2.75 per metric ton for floating conveyors compared to $1.50 to $1.75 per metric ton for on-shore export elevators.

Third, direct transfer requires that a uniform quality of grain be loaded into every rail car or barge, since direct transfer implies no blending. Thus, the shipping elevator or elevators must be responsible for shipping a uniform quality equal to that specified in the loading documents.

Fourth, direct transfer from one modal container to another may create grading and inspection problems in insuring the quality of the grain after the direct transfer.

- Bagging

Another technology to maintain identity preservation is bagged grain. Export bagging facilities are currently in place at export elevators in Corpus Christi, Texas, Houston, Texas, and Pascagoula, Mississippi.

The bagging operation consists of placing 50 kilos of previously graded grain into bags, sewing the bag shut, placing it on a pallet and transferring the full pallet to a warehouse on the dock to await loading into a vessel.

Most of the bagging of grain is for P.L. 480 shipments of 1,000 to 4,000 tons per order. The cost of bagging and loading the bagged grain is substantially higher than for bulk grain. The bagging operation, including moving the full pallets to a warehouse, is about $14.30 per metric ton. The cost of stevedoring or loading the pallets on to the vessel is $13.00 per metric ton. Thus, the total cost is about $27.30 per metric ton compared to less than $1.00 per metric ton for stevedoring bulk grain.

Grain Quality Control Strategies

Grain for Animal Feed

A large percentage of U.S. corn exports is used to manufacture animal feed in importing countries. Export sales for this use are extremely price sensitive. Thus, these exports must move through the conventional high speed, low cost grain distribution system to help keep U.S. grain competitive in world markets. One strategy for maintaining the quality of grain exported for animal feed use is to emphasize proper loading procedures at the export port, and proper unloading and handling procedures in the importing country. Proper loading and unloading procedures will minimize damage to the grain and will help provide for uniform quality of the sublots delivered to each end user.

Develop Special Low Cost Transportation-Distribution Systems to Accommodate Special Grain Quality Needs

The grain quality needs and transportation-handling possibilities vary among end users. To meet these end user needs, the special grain quality needs of individual end users must be identified. Then special low cost transportation-distribution systems like containerization or ship hold separation can be made available to these end users. Each end user will then have the option of buying bulk grain through normal distribution channels or buying and receiving grain that meets their special quality needs at prices that include the additional transport-handling costs.

Develop Policies to Encourage Reductions in the Number of Grain Handlings

Possibilities include:

a. encouraging mergers or consolidation of grain elevators located on abandoned rail lines with elevators located on rail lines. If the operations of these two types of elevators are consolidated, farmers could be encouraged, through price differentials, to deliver just enough grain to the non-rail elevators to meet truck shipment demands. The balance of the grain could then be delivered to the elevator located on rail lines for shipment.

b. encourage uniform quality shipments from country elevators and subterminals so that grain can be transferred directly into barges or into ocean vessels without being unloaded into elevators for blending.

c. continue to find ways to reduce the cost of shipping grain through the existing commercial system as well as in systems designed to meet special quality needs. For example, elevators located on abandoned rail lines could be closed or operated only during harvest season. This would encourage farmers to delivered their grain directly to low-cost elevators located on rail lines and eliminate the cost of operating duplicate facilities. However, this strategy may not be economic for all farmers in all locations.

Develop Methods for U.S. Exporters to Profitably Assume Some Responsibility for Grain Quality During Ocean Transit

Possibilities include:

a. negotiating sales contracts that specify terms to allow U.S. exporters to exercise more control over ocean vessel condition, loading and unloading,

b. negotiating grain quality standards that differ from FGIS standards and obtaining wavers from FGIS inspection,

c. developing procedures for exporters and importers to settle difference between loaded qualities at export ports and unloaded qualities at import ports.

All of these possibilities are currently available through negotiation of individual contracts.

Research and Education Needed to Implement Strategies to Preserve Grain Quality During Transit

The following are research needs to find ways to limit grain quality deterioration while moving through the grain transportation and distribution system:

- Assuming that grain grades and standards are revised into a larger number of grade options, research is needed to determine which level of the distribution system can accumulate the several grades at the lowest cost. A reasonable hypothesis is that the large country elevators and subterminals with numerous large bins would have the capacity to accumulate and maintain separate holdings of the multiple grades of grain. Furthermore, country elevators and subterminals would have a ready feed market for the low quality grain and screenings. Finally, transportation costs would be minimized if the low grade grain and screenings were never shipped to the processor or export port. However, this hypothesis needs testing with actual cost data.

- Research is needed to determine whether the cost of the alternative identity preservation methods can be reduced to a level that will encourage end users with special quality needs to purchase identity preserved grain rather than bulk grain through regular commercial channels.
- An examination should be made of the economic feasibility of constructing modern grain unloading and reblending facilities at importing ports to insure that all individual end users obtain the same quality of grain.
- Research is needed to evaluate alternate ship loading procedures to minimize the concentration of fine materials.
- Research is needed to examine possible methods of solving the logistics problems associated with direct transfer of grain from mode to mode without storing it in a grain elevator.
- Research is needed to determine the impact of revised grain grades and standards on operating and investment costs and ultimately on the competitiveness of U.S. grains in world markets.
- A major educational program is needed to inform importing end users of the need for improved unloading and distribution procedures in importing countries. This program should demonstrate that a major cause of the lack of uniformity of

sublots and the large increase in material over the FGIS loading certificate is the unloading and distribution procedures used by buying grain merchants or government agencies. This program would encourage end users to apply pressure for changes in these procedures. While improvements in unloading and distribution methods in importing countries would benefit all grain exporting countries, U.S. agriculture would receive the largest benefits from this program because it is the largest grain exporting country and because U.S. grains--particularly corn--are probably more susceptible to damage from improper unloading and distribution procedures than corn from other exporting nations.

- An educational program is needed to inform longshoring personnel of the impact of alternative loading procedures on grain quality. An incentive program could be initiated to encourage the use of the proper loading procedures at export ports.

Hill (1986) suggests that transportation and handling of grain from farm to final destination have a profound defect on the quality of grain delivered to the foreign user. The responsibility for the quality losses with a few exceptions does not reside with the transport firm or even the grain handlers. The quality problems are created by a system of grades and pricing practices that fail to provide economic incentives for maintaining grain quality. This suggests that research designed to develop strategies to preserve grain quality during transit should be coordinated with research on grain grades and standards.

Summary

The current U.S. grain distribution and transportation systems were designed for high speed, low cost operations which do not readily accommodate special quality needs of many grain buyers. However, there are several options, most of which are more costly, which can be implemented to provide higher quality grain for special uses. Moreover, there are research and educational opportunities to make the existing grain distribution system more grain quality oriented and to reduce the costs of alternative systems to provide special quality grains.

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Background Paper No. 9

Grain Quality Attributes for Corn Dry Milling

Marvin R. Paulsen
University of Illinois

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Figure 2. Beall degerminator showing auger intake section (left), knob-like protrusions (center), studded roll at discharge end (right). From: Beall Product Literature. Union Iron Works. Decatur, IL.

GRAIN QUALITY ATTRIBUTES FOR CORN DRY MILLING

INTRODUCTION

Dry milling of corn is generally achieved by either a grinding process or a tempering-degerming process. In early days and to a small extent today, whole corn is ground resulting in a product with high fat contents and a relatively short shelf life, Hoseney (1986). Since nearly all corn dry milled today is milled using the tempering-degerming process, the scope of this study will be limited to the degerming method. The alkaline dry milling process for snack foods is beyond the scope of this study, although most of the same quality characteristics that are desirable for alkaline dry milling processes are also desirable for dry milling.

The desired result of the degerming dry milling process is to obtain complete removal of the hull and to separate the germ from the endosperm. Unfortunately, complete separation of all parts of hulls and germs from the endosperm is very difficult and successive grindings of the endosperm product followed by aspiration and sifting is required to remove hulls and germs. Typically, corn kernel parts by weight consist of the germ 11 %, hull 5 %, tip cap 1 %, and endosperm 83 %, Watson (1987). The endosperm consists of an outer layer of yellow corneous or hard endosperm and of an inner pocket of white floury or soft endosperm. A high ratio of corneous to floury endosperm indicates corn is hard. Since the germ contains about 33 % oil, even small pieces of germ left attached to the endosperm add fat to the endosperm products, namely grits, meal, and flour. Thus, complete germ separation is desirable because: a) oil is the highest valued product, and b) oil or fat left in the grits, meal, or flour portions will shorten the storage life of the product. Of the white goods products, grits, meal, and flour, it is desirable to maximize the yield percentages of the large flaking grits. A complete description of the dry milling products will follow in a later section.

HISTORY OF CORN DRY MILLING

The overall quantity of corn that is dry milled and alkaline cooked annually in the United States is about 161 million bu or 4.09 million metric tons, Table 1. This quantity went from 154 million bu in 1975 to a high of 170 million bu in 1982, to 161 million bu in 1986. The small yearly changes reflect a mature industry. USDA (1987) reported small increases in the use of corn flour, meal, and cereal each year; but they analyzed that the use of corn in brewers grits was lessening because of a consumer trend toward light beers that use less corn and because of increased usage of rice in brewing.

Dry milling utilizes about 2 % of the total U.S. annual corn production, Table 1. In 1965, there were 152 dry corn mills in the U.S. with a daily capacity of 90 bu or more, Brekke (1970a). By 1969, the number of corn mills dropped to 115 and in 1984 there were 88 corn mills operating, Alexander (1987). In 1986, there were 68 mills operating. Of these 68 mills, 56 have daily capacities of under 12,000 bu, 7 have capacities between 12,000 and 36,000 bu/day, and 5 have capacities over 36,000 bu/day, Milling Directory (1987). The locations and capacities of 12 of the bigger plants are given in Table 2. These 12 plants have an estimated milling capacity of 430,000 bu/day which corresponds to about 100 million bu/year.

DESCRIPTION OF THE DRY MILLING PROCESS

To better understand why corn quality factors affect dry milling yields and output product quality, it is necessary to first describe the basic dry milling process. The steps in a general dry milling process include: cleaning, tempering, degerming, drying and cooling, aspirating, sifting, rolling, and oil expelling, Watson (1977). The flow chart shown in Figure 1 illustrates a typical tempering-degerming dry milling process.

Cleaning and Tempering

As corn first enters a dry mill it is cleaned by passing the corn over vibrating screens and under magnets to remove any possible tramp metal. In the cleaning process, corn is scalped to remove large pieces of cobs and other materials, and it is aspirated to remove dust and light particles. In some mills, corn is next washed with water and dewatered. Solids are removed from the wash water and added to the hominy feed by-product. Next, kernels are injected with steam or sprayed with warm water in a tempering auger-like chamber. Water temperatures used vary from room temperature up to about 120 F. The tempering may occur in one to three stages with corn finally reaching 18 to 22 % moisture w.b. (wet basis). The moist corn is held in tempering bins for up to 6 hours before processing further. Tempering allows moisture to diffuse into the kernels, causing pericarps (hulls) to soften and the endosperm to become more pliable. A guideline given by a major degerming company is that to maximize recovery of -3.5 +16 grits (particles passing through a 3.5 mesh and retained by a 16 mesh/inch sieve), a 20 to 22 % moisture tempering is needed. Moisture contents and tempering times are critical for obtaining correct moisture gradients in the kernel for achieving efficient degerming.

Degermination

Degermination is the process by which the softened pericarp and endosperm are broken apart from the germ. A few companies use impact mills or granulators for degermination, however, about 90 % of the degerming dry mills use Beall[1] degerminators which were introduced in 1906 in the United States, Brekke (1961), Brekke

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[1] Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by the author, the University of Illinois, or the Office of Technology Assessment and does not imply approval of the named product to the exclusion of other products that may be suitable.

(1970a) and Alexander (1987). One of the advantages of the Beall degerminator is the relatively high yield of flaking grits obtained. The Beall degermer is a cone shaped mill with rows of small 0.375 in. long conical protrusions that rotate at 700 to 900 rpm with about 0.5 in. clearance to a stationary outer conical surface which also has protrusions, Figure 2. The protrusions cause corn-on-corn rubbing until the product leaves the large axial end of the degerminator as tail stock, or it leaves through 0.25 inch diameter perforated plates along the bottom and side of the degermer as through stock. This rubbing type of attrition causes about 60 to 75 % of the entering corn to be discharged as through stock, Brekke (1970a). Through stock consists primarily of germs, pericarps, fines, and a few grits. Tail stock consists primarily of grits, and preferably of large grits that are free of attached germ or attached hulls. Brekke (1970a) reported that the rubbing of the corn across the screen perforations in the stationary part of the degermer, causes grits in the through stock to be scraped and sheared resulting in additional pericarp and germ removal. Discharged products are about 25 F warmer than when they entered due to the compressive work performed on the products.

Drying and Cooling

After degermination, through stock is normally wetter than tail stock, but both must be dried down to a moisture in the range of 15 to 18 % for rolling and fractionating. Steam-tube driers may be used to quickly dry the products by heating them to temperatures of 140 to 160 F, Brekke (1970a). The effect of this heating on possible stress crack formation in the grits will be reported in a later section. Next the stock is cooled to temperatures of 90 to 100 F.

Aspirating, Sifting, and Rolling

After the degermination process, both tail stock and through stock are dried and cooled. The tail stock contains primarily large pieces of endosperm while the through stock contains germs, some hulls, and small pieces of endosperm. Brekke (1970a) measured the typical products and relative yields obtained in tempering-degerming dry mills, Table 3. Uses of the products will be discussed in the next section.

Tail stock

Tail stock is aspirated to remove any loose hulls, then it is sifted so that material passing through a 3.5 mesh/in. sieve and retained on a 5 mesh sieve (-3.5 +5) is considered to be large flaking grits. (Some sources consider -3.5 +6 to be flaking grits, Table 3.) Any whole or nearly whole kernels that are retained on a +3.5 are recycled for retempering and degermination. The smaller fractions passing through the 6 mesh sieve and remaining on top of a 10 mesh sieve (-6 +10) and (-10 +14) sieve products are used for brewers grits or coarse grits, respectively. If there is any attached germ or attached hulls, the fractions will be rolled. The corrugated rollers have 6 to 30 corrugations per inch of circumference. Smaller numbers of corrugations are used for first break mills to produce coarse grits; while second and third break mills use rollers with more corrugations, resulting in a more finely ground product. Rollers are usually 9 inches in diameter and range in length from 24 to 36 inches. One of the rollers turns faster than the other to create extra abrasion for freeing hulls and germs from the endosperm. After rolling, the materials are sifted on plansifters consisting of one to seven flat woven wire sieves operating with a gyratory motion, followed by aspiration, and in some cases gravity tables. Gravity tables separate particles by density and aerodynamic properties. Air flows through a perforated sloping table that oscillates, aid in density separations.

Through stock

Through stock primarily contains germs which are aspirated to remove loose hulls, then the through stock is sent to a gravity table to separate germs, Figure 1. Germs are then dried and sent to an oil expeller or to a solvent oil extraction process to recover crude oil. The spent germ or germ cake from the oil extraction process is sent to a hammer mill and used in the hominy by-product for feed. Brekke (1970a) reported that recovered crude oil varies from 0.3 to 1.0 lb/bu of corn, with 0.6 to 0.8 lb/bu being common.

On the other side of the gravity table, any combined pieces of germ, endosperm, and hull are sent to either first or second break roller mills with the tail stock product.

USES OF PRODUCTS OBTAINED FROM DRY MILLING

Flaking Grits

A description of basic uses of the products that were listed in Table 3 is shown in Table 4. Flaking grits are the highest valued grit product and are used primarily to produce corn flakes. While general food uses account for 1,125 million lbs of dry milling product (Table 4), breakfast cereals account for most of the food uses.

Corn flakes are produced from a mixture of flaking grits, syrup, sugar, malt, salt, and water which is pressure cooked for 1 to 2 hours, Rooney and Serna-Saldivar (1987). Grits have a translucent appearance and their starch is gelatinized during cooking. Grits are then dried at 150 F to 19 to 20 % moisture, tempered for 6 to 24 hours, and passed through flaking rollers. Flakes are then toasted for 1 to 3 min. at 550 to 575 F. Toasted flakes are cooled, sprayed with nutrients and packaged, Rooney and Serna-Saldivar (1987).

Extruded flakes can also be produced in an extrusion process using corn flour. However, the texture and flavor of extruded flakes are different than that of the rolled flakes from large grits, Rooney and Serna-Saldivar (1987). If a consumer trend away from the rolled flakes were to occur, it would have a major impact on the present need for large flaking grits. However, in spite of new extrusion technology, it has not been possible to produce extruded flakes with the same crispness and texture as in conventionally cooked corn flakes, Kirleis (1988). Thus, the demand for large flaking grits is expected to continue and has dictated the need for the present tempering-degerming dry milling processes as we know them today.

Coarse and Regular Grits

Coarse and regular grits are used in the brewing industry for beer production. Brewing use accounted for an estimated 1,850 million lbs in 1977, Table 4. This usage may have declined to some extent because of trends toward light beers, increased usage of rice, and a shift toward rice and corn syrups for fermentable sugars for brewing, Alexander (1987).

Meals

Corn meals are made from the material that is too small to make grits. They have a relatively long shelf life, and are free of black specks (from the corn hilar layer), Rooney and Serna-Saldivar (1987). Corn meals are used for corn bread, muffins, fritters, hush puppies, breading mixes, and stuffing. Meals are also consumed as partially cooked cornmeal used in PL 480 food programs. Corn meals are also utilized in breakfast cereals, snack foods, and extrusion puffing products.

Flours

Corn flour is made from the finely ground starchy endosperm. It is used in mixes for pancakes, muffins, doughnuts, breadings, batters, and in ready-to-eat breakfast cereals, snacks, and as a binder for processed meats, Rooney and Serna-Saldivar (1987). They are also utilized as an ingredient in corn-soy milk blends and in extruded snack food products.

Corn flour also has many industrial uses which include items such as: 1) gypsum board binders from acid-modified corn flour; 2) corn-flours used in the production of insulation, fiber board, plywood, and laminating adhesives, particle board, and wafer board; 3) pharmaceutical-fermentation products using corn flour to produce citric acid; 4) fermentation of corn products to make industrial alcohol; 5) foundry binders using precooked corn flour; 6) charcoal briquets using corn flour as an adhesive; 7) paper using additives to improve strength and pigment retention; 8) corrugating adhesives and general adhesives using corn flour; 9) ore refining using corn flours; 10) oil well drilling mud using precooked corn starch to minimize water loss in the drilling mud; and 11) thermoplastics and polyurethanes using corn flour as extenders in polyvinyl alcohol and polyvinyl chloride films used as agricultural mulches; Alexander (1987).

Corn Oil

Corn oil is obtained by an expelling process or by hexane extraction from the germ. Corn oil is the highest valued product obtainable from dry milling. Thus, it is desirable to obtain maximum oil; but failure to obtain high germ separations also gives a negative value to the grits and products in which the oil is left. Brekke (1970a) reported that typical percentages of oil left in flaking, coarse, and regular grits are about 0.7 to 0.8, Table 3. The meals contain about 1 % fat, while flours may contain about 2 % fat.

Hominy Feed

Hominy feed is the product that is comprised of all the by-products, such as pericarp fractions, unseparable mixtures of hulls, endosperm, and germ, spent germ, and corn cleanings or BCFM, Watson (1977). It accounts for about 2.2 billion lbs annually and is the single largest product sold by dry millers, Alexander (1987), Table 4. He reported that hominy provides a high-fiber, high-caloric material that is also high in carotenoids (yellow pigment) and high in vitamins A and D. Various milling companies have tried marketing some of the hominy by-products such as corn bran (hulls) and spent germs individually. Alexander (1987) reported that hominy meal at 13.5 % moisture, contained about 8.0 % protein, 3.4 % fat, 4.7 % crude fiber, 2.0 % ash, 61.0 % starch, and 7.4 % other polysaccharides. When this hominy meal is blended with BCFM removed earlier, the composition of the standard meal at 14.0 % moisture is 11.0 % protein, 4.5 % fat, 2.5 % crude fiber, 2.0 % ash, 60.0 % starch, and 6.0 % other polysaccharides. Hominy feed is a source of good quality protein and energy and is used as an ingredient in poultry, swine, and cattle feeds.

QUALITY FACTORS AFFECTING DRY MILLING

There are several corn quality factors which affect dry milling performance, yields, and quality of products derived from dry milling. Those factors include corn hardness (related to varietal characteristics and density), drying temperature (moisture removal rate), stress cracks, moisture content, kernel size and shape, broken corn and foreign matter (BCFM), and wholesomeness or freedom of incoming corn from mold, aflatoxin, insects, rodent excreta, toxic substances, odors, etc.

Corn Hardness and Varietal Factors

Effects of Corn Hardness

Corn hardness can be defined as the quantity of corneous, horny endosperm contained in a corn kernel relative to the amount of floury endosperm. Cutting a kernel open and visually examining it provides a good indication of hardness but provides subjective information that is difficult to categorize, Paulsen et al. (1983). Wolf et al. (1952) reported that the ratio of corneous to floury endosperm averages 2:1 in dent corn. Typically, corn such as flint corn grown in Argentina is of maximum hardness and has a corneous/floury ratio greater than 2:1. On the other end of the scale, corn such as Opaque 2 or high lysine corn would have maximum softness, Coe and Neuffer (1977). Corn hardness is almost entirely a result of corn genotype or varietal selection; but to a limited extent high Nitrogen soil fertility and drought conditions are two environmental factors that also tend to cause corn hardness to increase. Dry millers have repeatedly stated that they need a hard corn if they want to produce high yields of large flaking grits. Many now have approved lists of hybrids that they have found acceptable for their operations.

Another effect of corn hardness is a general increase in kernel density or in test weight (bulk density) as hardness increases. Rutledge (1977) stated that test weight was important because it indicates whether corn is of a hard, flinty endosperm type. He stated low test weight corn is soft and contains a high percentage of floury endosperm which mills into higher percentages of the lower grade products. Thus, corn variety selection is the primary way by which corn hardness can be changed.

Kirleis et al. (1985) developed a milling evaluation factor (MEF) for a short-flow laboratory dry milling procedure. They found MEF had a significant correlation (+0.84) with commercial dry milling production of No. 4 flaking grits. Factors they found to significantly correlate with MEF were test weight, kernel density, and visual hardness ratings.

Paulsen and Hill (1985) segregated corn into four lots of high and low test weight and high and low breakage susceptibility over a one year period. Each lot consisted of over 70,000 bu which was then processed through a full-size dry mill over a one-day period.

Highest flaking grit yield (16.05 %) was obtained with the high test weight and low breakage susceptibility corn. Lowest flaking grit yield (7.84 %) was obtained with low test weight and high breakage susceptibility corn. A significant correlation (+0.95) was obtained between test weight and flaking grit yield. Thus, test weight correlates quite well to flaking grit yields.

Kirleis et al. (1986) dried soft, medium, and hard corn genotypes at temperatures of 27, 38, 60, 82, and 93 C from 25 % to 14 % moisture content. They found MEF decreased for each hybrid as drying temperature increased. MEF was found to best correlate with alcohol density tests (+0.87), test weight (+0.86), and the Stein breakage tester (-0.78) at the 0.01 level of probability. They obtained a non-significant correlation of -0.16 between MEF and stress crack index (SCI = 1 x No. of single cracks + 3 x No. of multiple cracks + 5 x No. of checked kernels). The erroneous conclusion that MEF or flaking grit yield is not affected by stress cracks, could be drawn from this study if one fails to consider that widely varying corn hardness genotypes were used. There is a tendency for hard endosperm genotypes to stress crack more easily than soft genotypes. The analogy could be made that hard endosperm is more brittle and thus, more likely to develop stresses due to thermal and moisture gradients. Therefore, when the same corn genotype is being milled, hardness stays constant and increases in stress cracks are indicative of higher drying temperatures and the highly stress-cracked corn will produce low flaking grit yields. However, if corn hardness varies due to genotypes, then one can expect the hard corn to out produce the flaking grit yield of the soft corn regardless of how many stress cracks are in the hard corn. Thus, hardness is the primary factor that must be present to obtain high flaking grit yields and low stress cracks would be a secondary factor.

Measurements for Corn Hardness

Test weight is one commonly used measure of corn hardness. Another measure is the floaters test. Manokarkumar et al. (1978) performed floaters tests using a 1.275 specific gravity solution on 20 maize varieties that were harvested at 35 % and dried with 60 C air to 15 % moisture. They found floaters percentage to be significantly correlated in the negative direction with brewers grit yields. The floaters test consists of placing 100 whole kernels into a 1.275 specific gravity solution and counting the number of kernels that float. A high number of floaters indicate a soft corn.

Wichser (1961a,b) stated that the floaters test is related to the alcohol soluble nitrogen content of corn. Corneous endosperm contains more zein (which is alcohol soluble) than does floury endosperm; thus, the floaters test provides an indication of corneous endosperm. He used a 1.275 specific gravity solution of carbon-tetrachloride and kerosene. However, the toxic vapor and high volatility of carbon-tetrachloride does not make it the best choice of solutions. Solutions of tetrachloroethylene and deodorized kerosene or of sodium nitrate and distilled water have been commonly used for the floaters test.

A simple test for true density can be performed using a alcohol column test. The test involves placing preweighed sample of 100 whole kernels into a graduated cylinder containing alcohol. The volume displaced divided by the kernel weight provides density in g/cm^3.

Other tests that indicate hardness include tests for grinding resistance and particle size distributions. The Stenvert hardness tester uses a micro-cutter hammer mill to pulverize a 20 g sample enough to pass through a 2.0 mm sieve. Since hard corn grinds more slowly than soft corn, the time to grind into a 17 ml collection tube provides one measure of hardness, Pomeranz et al. (1985). Since hard corn tends to grind into coarser particles than soft corn, ground corn samples placed into a near infrared reflectance (NIR) machine tend to absorb more infrared light if particles are coarse. The difference in light reflectance is measurable on an NIR instrument. The Stein breakage tester uses a combination of small repeated impacts and abrasion on a 100 g sample for a period of 2 min. Kirleis et al. (1986) has found the Stein tester to be negatively correlated (-0.78) with a dry milling evaluation factor.

Drying Temperature and Stress Cracks

Effects of Drying Temperature

Excessive drying temperatures lead to corn kernel stress cracking which can have deleterious effects on dry milling yields.

Substantial effects of drying temperature on laboratory-scale dry milling yields were found by Brekke et al. (1973). In their study corn was dried in a fluidized bed dryer with air heated to 90, 140, 190, 240, and 290 F. The control was bin-dried at ambient temperatures of 35-60 F. Corn was dried from 25 to 15 % moisture content. The whole corn initially contained 4.6 % fat and 10.3 % protein on a dry basis. Kernel size was such that 50 % were retained on a 21/64 in. round-hole sieve. Corn was pretempered to 16 %, then tempered to 21 % one hour before degerming. A third temper raised moisture to 23-25 % just 15 min. before degerming. A Beall degerminator and dehuller was adjusted to give 5 % whole kernels on a +3.5 sieve for recycling. As drying temperature increased from 35-60, 90, 140, 190, 240, to 290 F, the first break grit yields went down from 19, 14, 10, 8, 7, to 4 %, respectively, Table 5. Fat contents of the first break grits increased from 0.5 to 0.8 % db as the drying air temperature increased. Brekke et al. (1973) stated that the source of fat in grits is normally due to the presence of germ particles attached to the grits due to incomplete degerming. In general, the results in Table 5 show that drying temperatures above 60 F, greatly reduce first break grit yields, and yields continue to decline with each increase in temperature. Thus, increases in drying air temperature even above ambient air conditions cause a reduction in flaking grit yields.

Brekke et al. (1973) also measured corn kernel stress cracks and documented their increase from 7 % for corn dried at 35-60 F to 84 % at 290 F. The ratio of multiple stress cracks to single cracks was also found to increase with drying air temperature; thus, indicating temperature not only increases stress cracks but also increases the severity of stress cracking, Table 5.

Roberts (1972) reported that heat damage as described in the U.S. Corn Grading Standards consists of a visual discoloration of the kernel which does not occur until grain temperature exceeds 180 F. Furthermore, he reported that at temperatures above 140 F, there were three detrimental effects produced on the corn kernel. Those were: 1) a reduction in the fermentable carbohydrate content; 2) a reduction in the corn nutritive value for rats; and 3) a reduction in efficiency of separation of starch and protein for wet milling. Since brewers grits are one of the dry milling products, dry millers are concerned about reductions in fermentable carbohydrates.

Roberts (1972) also reported that of 109 incoming truckloads of corn, stress cracks averaged 28 % for undried corn. For corn dried at unspecified high temperatures (24 farm-dried and 41 elevator-dried samples), kernels with single or multiple stress cracks averaged 90 %. He stated that stress cracks were undesirable due to a greater tendency for breakage during handling and likelihood of mold invasion. However, he presented two views on the effect of stress cracks on the milling operation. The first view was that since the degermer breaks the whole kernel into about four pieces of endosperm; then when any highly stress-cracked corn is passed through the degermer, the endosperm breaks along the stress cracks lines causing more small-sized endosperm pieces, which reduces the yield of large flaking grits. The second view was that the endosperm did not initially break along the stress crack lines, because stress cracks were still found in the flaking grits. (It is possible that some of the stress cracks found in flaking grits were newly created by the rapid drying treatment obtained in the plant after degermination.) Regardless of which view is taken, the end result of having stress cracks in the flaking grits is undesirable; because stress-cracked grits will easily break into smaller grits when undergoing cooking and pressing through the flaking rolls.

Measurements of Drying Temperature

One of the mentioned effects of corn drying temperature is the prevalence of stress cracks in the corn kernels. The primary method for measuring stress cracks is to place 50 g of whole kernels over a bright light and candle them to visually find fissures in the endosperm, Thompson and Foster (1963). The numbers of kernels with no stress cracks, one crack, or multiple (checked) cracks are determined.

An indirect measure of stress cracks can be obtained with the Wisconsin breakage susceptibility tester. With this machine, a pre-sieved sample of 200 g is passed through a rotating impeller that centrifugally propels individual kernels against the inner surface of a 10 in. I.D. chamber. Kernels receive one major impact and fall downward to a collection pan. The sample is re-sieved on a 16/64 in. round hole sieve. The percentage of breakage susceptibility is computed as 100 x breakage weight / original weight.

Paulsen and Hill (1985) found that percentages of stress cracks in incoming corn to a dry milling plant were significantly correlated (+0.99) to breakage susceptibility values obtained from a Wisconsin breakage susceptibility tester using a 16/64 in. round hole sieve. Thus, the breakage susceptibility test was found to provide a faster means of indirectly evaluating stress cracks.

Another method of determining drying temperature is the warm germination test. Brekke et al. (1973) found germination decreased from 85 to 0 % as drying temperature increased from 35-60 to 290 F. General guidelines used in the seedcorn industry for maintaining germination dictate that drying temperatures should never exceed 105 F. Thus, if a sample is not moldy and germination is lost, it may indicate that drying temperature exceeded 105 F. However, it is possible to exceed 105 F without making corn totally unsuitable for dry milling. Tests for protein denaturization may be helpful. Chemical tests such as for ethanol soluble protein or Nitrogen Solubility Index (NSI) will indicate whether corn has been heated enough for protein to denaturization to occur. Peplinski et al. (1975) reported that NSI levels increased significantly from 5.8 % to 9.8 % as drying temperature decreased from 300 to 120 F.

While drying is a necessary step to prevent corn spoilage, drying methods that cause high kernel temperatures lead to rapid moisture removal which result in stress cracks in the kernel. Drying methods such as low temperature drying (10 F maximum above ambient air temperature) or some of the newer commercial dryers that use the concurrent flow principle (wet grain is exposed to the highest temperature air, but evaporative cooling keeps wet corn kernel temperatures low) can use high air temperatures without allowing kernel temperatures to reach excessive levels. Such drying methods are able to keep stress cracks lower than conventional crossflow dryers.

Moisture Content

The degermination process is dependent on having the proper moisture gradient in the corn kernel to permit the degerming operation to occur. Brekke (1968) reported that old crop corn having moisture contents below 15 % often fails to temper properly under the normal tempering conditions used. Rutledge (1977) also stated that moisture was important. Corn dried below 12.5 % tempers differently than wetter corn and if not tempered properly, efficiency will be lost in the germ separation process.

Brekke (1968) tempered corn at moistures of 10.1, 13.5, and 14.6 % up to 20.1 % moisture and measured stress cracks formed over time. Stress crack levels were higher as tempering time increased. And stress crack levels were much higher for the 10.1 % corn than for the 14.6 % corn. He also found that if temper temperatures were at 125 F, no stress cracks were formed. At temperatures of 85 F, a 6 hr temper produced about 75 % stress cracks for corn tempered from 13 % to 21 % moisture. He determined that yield of -4 +6 grits increased from 34 % to 41 % of net product, as stress cracks decreased from 48 % down to 4 %. Degerminator throughput went from 41 bu/hr to 16 bu/hr and oil content in the -4 +6 grits decreased from 0.7 % to 0.4 % db as stress cracks decreased from 48 % down to 4 %. In another study, Brekke (1966) reported that if corn was tempered from 12-13 % moisture all the way to 21 % in one temper, a large number of kernels develop stress cracks. With higher stress cracks degerminator capacity increased, but yields of flaking grits were reduced and more oil was left in the grits. Thus, to increase flaking grits, it was desirable to perform tempering in two or more stages. Brekke (1967) reported that pretempering was more advantageous for natural-air dried corn than for artificially-dried corn. Since artificially dried corn was already high in stress cracks, pretempering could not effectively reduce or remove stress cracks that were already present.

Thus, warmer temperatures for tempering and multiple temperings for low moisture corn reduced stress cracks and provided a higher quality product, but at the expense of reduced throughput in the degermers. These results also support the view that increased stress cracks reduce the yield of large flaking grits.

Broken Corn and Foreign Material

Broken corn and foreign material is detrimental for dry milling. BCFM increases with handling. However, the increases are usually greater if corn has been dried at high temperatures, resulting in high levels of stress cracks, or if corn moisture contents are low. Usually no attempt is made to use BCFM in the milling process. It is removed by screening prior to processing. Roberts (1972) stated that mechanically damaged corn will have lower yields of prime products. Small broken kernel portions are removed prior to milling and are diverted to hominy feed. Since hominy feed sells for about 85 % of the cash price of corn, the dry miller looses margin on corn with high BCFM, Milling and Baking News (1987). Rutledge (1977) reported that they remove BCFM with a 16/64 in. sieve and that any material passing through the sieve ends up as hominy feed which sells for less than whole corn price.

Kernel Size and Shape Factors

Dry millers report that round corn kernels are more difficult to degerm than the flat kernels from the center of the ear. Kirleis (1987) reported that short kernels provided higher milling evaluation factors than long kernels. Pomeranz et al. (1985) found that the time to grind on a Stenvert mill was greater for round kernels than for flat kernels.

Wholesomeness Factors

Corn used for dry milling is by nature used largely for human consumption. Dry mills are routinely inspected by personnel from the Food and Drug Administration, Wichser (1961b). Dry millers are obviously concerned that clean, wholesome corn is brought into the plant. Roberts (1972) expressed concern about corn that may be moldy or stored at moistures high enough to allow mold growth. Aflatoxin and mycotoxins are of concern and aflatoxin levels, as set by the Federal Food and Drug Adminstration, must be less than 20 ppb in any food product. In years when aflatoxin is a problem in corn in a particular growing region, dry millers will inspect incoming corn first using a ultra violet black light to detect any yellow-green fluorescence which may be an indicator of aflatoxin. If corn is suspect further testing will be done. An intact pericarp was given as one way to help reduce storage fungi invasion into the corn.

Rutledge (1977) reported that rodent excreta and rodent hairs occasionally were a problem. They inspect inbound corn and reject it if rodent excreta and rodent hairs are found. Granary weevils and rice weevils were also given as two insects of major importance. Both are internal feeders, which may not be noticeable initially but when ground, they may leave insect fragments in the finished product. Soybeans mixed into corn was also stated as an undesirable problem because the soybeans would likely be sieved into the flaking grits portion. Classes of corn consist of yellow, white, and mixed. Yellow corn can not contain more than 5 % of corn of other colors. White corn can not contain more than 2 % of corn of other colors. Each have distinct uses in dry milling.

TECHNOLOGICAL IMPROVEMENTS IN DRY MILLING

One of the technological improvements that has occurred in the dry milling industry over the last ten years is in the varietal selection of corn genotypes being dry milled today. About ten years ago the primary factor that plant breeders use for breeding selection was yield, disease resistance, and standability. A genotype, B73 x Mo17, became very popular in the Corn-belt states. Its yield was so good that nearly every seed company offered that genotype in at least one of their varieties. Unfortunately for dry millers, the hybrid was also very soft and flaking grit yields dropped drastically. Many dry millers became concerned and started their own test procedures for detection of corn hardness. Varieties with greater hardness were identified and plant breeders have worked to make available alternative varieties that are harder and still yield nearly as well as their softer counterparts; however, more work is needed.

Through the efforts of many University researchers, corn breeders, dry millers, and the NC-151 Research Committee on "Marketing and Delivery of Quality Grains and Oilseeds in Domestic and Foreign Markets", there are now hard corn varieties identified that are more suitable for dry milling, NC-151 (1988), Stroshine et al. (1986). However, more work is needed by corn breeders to actually breed for hard corn with acceptable yields, disease resistance, and standability. Unfortunately, there are still no universal standards for measuring corn hardness and each dry milling company has their own method that they use. More research is needed to identify and understand the biochemical factors that cause corn to be hard or soft. Greater knowledge of these biochemical factors would also benefit corn breeders when making crosses for hard endosperm phenotypes and would assist the genetic engineer in inserting genes for increased hardness.

Since corn hardness is the primary factor influencing flaking grit yields, an industry-wide accepted standard method for measuring corn hardness, would lower the cost for testing, allow commercial instruments to be built for testing, and provide a more cost effective means of directing the available supply of hard corn to a dry milling plant. While test weight is measured in the grading standards, there are other factors such as pericarp cracks, moisture content, and fine material that affect test weight in addition to density or kernel hardness. Thus, other tests are needed in addition to test weight.

There are other processes for degerming. Brekke (1964) compared the Beall degerminator (cone mill) to a disk mill and a granulation mill. Basically, the cone mill provided the best degermination and the most -4 +6 grits with less than 0.5 % oil. The disk mill obtained the most recoverable oil and the granulator obtained an intermediate amount of oil. All three types produced comparable quantities of -3.5 +16 mesh grits. The disk mill used less power per bu processed than the other mills. Both disk and granulator types can degerminate at lower moisture contents than the Beall degerminator. Wanzenreid (1986) reported that the Buhler-Miag Co. provides four systems, some of which do not require tempering, thus saving drying costs after degerming. System 1 does no tempering and provides full-fat meal and grits. System 2 tempers to about 15.5 % moisture and produces grits and meal over

1.0 % fat and removes germs. System 3 provides a higher germ extraction rate and less than 1 % fat in grits and meal, but uses a second tempering immediately before the decorticator. System 4 uses the Beall degerminator and two tempers. Wanzenreid (1986) reported that up to 25 % flaking grit yield was possible with this system but did not report how the flaking grits were defined.

Ocrim America Inc. is another manufacturer of dry milling equipment. They have four different degermination processes depending on the desired product output. Ocrim (1987) listed those processes as: 1) a dry process with an impact rotor degerminator and gravity tables (provides high quality germ and grits high in carotene); 2) partially wet process with conical rotor dehuskers (used for hominy grits used in corn flakes); 3) combined degermination using steam and octagonal rotor degerminators (used for production of brewers grits or snack grits); and 4) mixed degermination using impact rotor degerminators, roller mills, and sifters (for meal for polenta or porridge).

Basically, dry processes utilize less energy per ton processed, and save on product drying costs. However, to achieve large flaking grits, most domestic dry millers use the Beall degerminator even though it requires tempering to about 22 % moisture and more power to operate.

In general, most dry millers indicate that few technological changes are occurring in their industry. However, if major changes were underway, they would be of a proprietary nature and could not be discussed. It would be reasonable to conclude that efforts will continue to reduce energy costs whenever an acceptable product can be produced using less energy.

EMERGING AREAS AFFECTING DRY MILLING TECHNOLOGY

The dry milling industry is a very mature industry which primarily supplies food products for human consumption. With relatively stable population growth in the U.S., dry milling production has remained fairly constant over the past 10 years, Table 1. Thus, it is not likely that sudden large changes in dry milling production will be needed or will occur in the near future. Since domestic dry milling production meets domestic food demand, there are conceivably two factors that could create new demands for large additional quantities of dry milled products. Those factors are: 1) a world-wide food/financial program that would cause huge exports of dry milled products to meet world-wide hunger problems; or 2) new or improved processes involving industrial uses of dry milled products.

Alexander (1987) reported that in the early 1960's, government food aid programs enabled the development of a corn-soy-milk (CSM) product for under developed countries. CSM contained 64 % partially cooked cornmeal, 24 % defatted toasted soy flour, 5 % nonfat dry milk, 5 % soy oil, and 2 % vitamins and minerals. Nutritionally CSM was well balanced with carbohydrates, protein, and fat. Food For Peace legislation (PL 480) was passed to provide food for malnourished people in Third World countries. From 1977 to 1982 about 400 to 547 million lbs of corn-based fortified foods have been sold annually to government agencies under PL 480, Alexander (1987).

Many of the industrial uses of corn dry milled products were previously listed. Corn flours are being considered for use in encapsulating herbicide pellets to provide slow release over the growing season. It should be noted that many of the industrial uses that involve corn flour are in competition with corn starch from the wet milling industry. Whereas, corn starch from wet milling is a highly refined and pure substance, corn flour in dry milling is the substance left over after all the hulls, germs, grits, and meal has been taken out. Wolff (1982) states that corn flour from dry milling still contains some protein and fat which causes the flour to resist gelatinization and become less soluble in water than corn starch.

Although large changes in domestic consumption of dry milling products do not appear likely, there will continue to be shifts in the way products are used. One of the emerging areas is a consumer shift toward more dietary fiber. Corn hulls are an important source of fiber and instead of adding hulls to hominy feed, this 5 % of the kernel has a higher valued market in high fiber cereals, high fiber breads and snack foods. As the fiber market develops it could also cause a shift toward corn varieties that in addition to being hard, also have a clear, non-colored hull.

Another changing area is that the demand for brewers grits is being partially replaced by rice, and rice and corn syrups. Syrups provide a higher concentration of fermentable sugars and therefore an increase in brewing capacity, Alexander (1987). Because of this change, more brewers grits are being used in snack foods.

In predicting future trends in dry milling, one area to watch is the new extrusion technology. Although not likely in the near future, if newer extrusion technology were able to produce a consumer-accepted substitute for corn flakes, it could diminish the need for flaking grits. High yield of flaking grits appears to be the primary reason for a tempering-degerming process and for the need for hard corn. If effective germ removal could be accomplished with less tempering it would reduce drying costs substantially.

SUMMARY

Dry milling is the process by which corn is separated into components of hulls, germs, and endosperm. The hulls are 5 % by weight, the germ is 11 %, the endosperm is 83 %, and the tip cap is 1 %. Since hulls and germs are not easily released from the endosperm, the corn is first tempered or re-moistened in stages to about 22 % moisture content which helps to loosen and soften the hulls. The corn is then degermed, aspirated, sifted, and rolled into successively smaller particle sizes, so that nearly all attached hulls and germs are separated from the endosperm. The ideal dry milling process will have low fat in the endosperm.

Corn dry milling combined with alkaline processing utilizes about 161 million bushels of corn in the United States each year. The quantity of corn dry milled has remained relatively constant over the past 10 years. Although there are about 68 dry mills operating in the U.S., many of the smaller mills grind the whole kernel. Most of the corn is processed through the 12 largest capacity dry mills which account for about 100 million bushels per year.

Of the corn quality factors important for dry milling, one must first assume corn wholesomeness or freedom from mold, aflatoxin, severe insect infestation, etc. because corn is being processed for food uses. Moisture content is of obvious importance because it determines how much dry matter is available for making products. Class of corn must also be known because yellow and white corn have distinct uses. After the above factors have been met, then the most important quality factor for dry millers is corn hardness. Corn hardness relates the amount of yellow corneous endosperm present in the kernel relative to the amount of floury endosperm. High ratios of corneous/floury endosperm enable higher yields of flaking grits to be obtained. Flaking grits are of higher value than the smaller grit sizes.

Corn which is hard is more dense, has greater resistance to grinding, and tends to grind into larger particle sizes than softer corn. These characteristics provide the physical means by which hardness can be measured. Many dry millers use test weight (bulk density) as a measure of hardness. Unfortunately, this test is also influenced by other variables such as moisture, fines, and pericarp damage. The floaters test also works on a density principle. Some millers prefer their own proprietary methods which probably involve a combination of grinding resistance and particle size determinations. The ability of dry millers to make use of any type of hardness test depends on their location relative to their supply of corn. Those located within the growing area can accept or reject corn by individual truckloads. Those that rely on unit trains from a distance, would be less inclined to reject a carload of corn because of loosing the unit train pricing structure.

The primary method for changing hardness is by variety selection. Some dry millers provide lists of selected hybrids that they have found to be hard and that they would be willing to buy. Except for snack food processors, few if any dry millers have yet contracted with farmers to grow certain hard varieties. There has been a considerable shift in the past five years to corn varieties that are hard and yields of many hard varieties are becoming competitive with yields of softer corn varieties. More effort, however, is needed by corn breeders to breed for new varieties with acceptable hardness, yield, disease resistance, and standability.

More research is needed to identify the biochemical factors affecting corn hardness, and an accepted standardized test for corn hardness is needed. Such a test would lower the cost for testing, enable commercial test instruments to be built, and would help provide a cost effective means of directing a dependable supply of hard corn to dry milling plants.

The next factor of importance is the percentage of stress cracks in the corn prior to entering the degerminator. Corn that is low-temperature or ambient-air dried is lower in stress cracks than corn dried at higher temperatures. However, the tempering process that the dry miller uses can also increase stress cracks if corn is tempered from low moistures to 22 % all in one stage. To reduce the possibility of creating stress cracks during tempering, two stage tempering and using warm water helps. Research indicates that high levels of stress cracks and particularly multiple or checked cracks, cause a low yield of large flaking grits, even though less degerminator power is needed. As drying temperatures increase, fat percentages in first break grits increase also, Brekke et al. (1973).

Further increases in drying temperature lead to protein denaturization which Roberts (1972) reported reduced the fermentable carbohydrate content of corn grits. Improved, faster methods for measuring effects of drying temperature are needed.

High BCFM levels in corn is probably less important that hardness or stress cracks, but its effect is felt more directly. The most apparent effect of BCFM is that it must be cleaned out of the incoming corn, and it is later added to the hominy feed that sells for about 85 % of the corn price. Thus, the loss is direct and easily measurable. An unknown consequential effect of high BCFM is that the same corn lot is likely to have a lower percentage of whole kernels. In the tempering process, non-whole kernels are likely to absorb moisture more quickly than whole kernels. Uneven moisture absorbtion would likely lead to non-uniform degermination and poorer germ and hull separation through the mill.

While the dry milling industry is fairly old and well established, a few trends are emerging. Some trends are an increased demand for the hulls for use as dietary fiber, reduced demand for brewers grits due to uses of rice and corn syrups for fermentation, and heavy uses of corn flours for industrial products. Extrusion technology for producing corn flakes has not gained wide-spread consummer acceptance, but should be watched. If extruded cereal products were ever to replace the corn flake market, there could conceivably be less need for the tempering/ Beall degerming process. Technology would still be needed to remove the germ, but other types of degerminators which require less moisture for tempering would reduce costs for drying the degermed products.

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APPENDIX

Table 1. Amount of Corn Used Annually for Dry Milled and Alkaline Cooked Products in the United States.

Year (Begins Sept.1)	Dry-Milled and Alkaline cooked Products, Million bu.	Total U.S. Corn Production, Million bu.	Dry Milling Percentage
1975	154	5,841	2.6
1976	155	6,289	2.5
1977	158	6,505	2.4
1978	155	7,268	2.1
1979	158	7,928	2.0
1980	160	6,639	2.4
1981	162	8,119	2.0
1982	170	8,235	2.1
1983	164	4,175	3.9
1984	160	7,674	2.1
1985	161	8,865	1.8
1986	161	8,253	2.0

From: USDA ERS. May 1987. Feed Situation and Outlook Report. FdS-302 Washington, D.C. 20005-4788 and USDA Agricultural Statistics, 1986. U.S. Government Printing Office, Washington, D.C. 20402.

Table 2. Plant Locations and Estimated Capacities of Principal Corn Dry Milling Companies.

Company	Mill Location	Estimated Daily Capacity, bu
Archer Daniels Midland	Lincoln, NE (Gooch Mills)	15,000
Evans Milling Co.	Indianapolis, IN	30,000
Illinois Cereal Mills, Inc.	Paris, IL	65,000
Archer Daniels Midland Co.	Milwaukee, WI	55,000
Bunge Corp.	Danville, IL	70,000
Bunge Corp.	Crete. NE (Crete Mills)	50,000
Bunge Corp.	Atchison, KS	45,000
Martha White Foods*	Jackson & Lebanon, TN	25,000
The Quaker Oats Co.	Cedar Rapids, IA	20,000
The Quaker Oats Co.	Chattanooga, TN	15,000
The Quaker Oats Co.	St. Joseph, MO	10,000
J. R. Short Milling Co.	Kankakee, IL	30,000
TOTAL		430,000

* Martha White Foods operate two corn dry mills at Lebanon and Jackson, TN. The capacity for each mill was listed as under 12,000 bu/day in the 1988 Milling Directory published by Milling and Baking News.

Table from: R. J. Alexander. 1987. Corn Dry Milling: Processes, Products and Applications. In: Corn Chemistry and Technology Edited by S. A. Watson and P. E. Ramstad. American Association of Cereal Chemists, Inc., St. Paul, MN. (Table was updated to reflect O.T.A. reviewers' comments.)

Table 3. Typical Yields for Corn Products from a Degerming Dry Mill.

Product	Yield %	Typical Particle Size	Moisture % WB	Fat % DB
Corn	100		15.5	
		Primary Products		
Flaking Grits	12	- 3.5 + 6	14.0	0.7
Coarse Grits	15	-10.0 + 14	13.0	0.7
Regular Grits	23	-14.0 + 28	13.0	0.8
Coarse Meal	3	-28.0 + 50	12.0	1.2
Dusted Meal	3	-50.0 + 75	12.0	1.0
Flour	4	-75.0 + Pan	12.0	2.0
Oil	1			
Hominy Feed	35		13.0	6.3
Shrinkage	4			
		Alternate Products		
Brewer's Grits	30	-12.0 +30	13.0	0.7
100% Meal	10	-28.0 + Pan	12.0	1.5
Fine Meal	7	-50.0 + Pan	12.0	1.6
Germ Fraction	10	- 3.5 + 20	15.0	18.0

From: Brekke, O. L. 1970. Corn Dry Milling Industry. In: Corn: Culture, Processing, Products by G. E. Inglett, editor, AVI Publishing Co., Inc. Westport, CT.

Table 4. Estimated Dry Milling Product Quantities Classified According to End Use for 1977.*

Use		Quantity million, lbs.	
Brewing			1,850
Food, general			1,125
	Breakfast Cereals	800	
	Baking	50	
	Snack Foods	100	
	Breadings, batters, baby foods, etc.	75	
Fortified PL 480 foods			485
Nonfood			530
	Gypsum board	100	
	Particle, Fiber board, plywood	40	
	Pharmaceuticals, fermentation	200	
	Foundry binders	90	
	Charcoal binders	75	
	Other (paper, corrugating, oil well drilling fluids)	25	
Animal feed			2,200
Total			6,190

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* Table is an estimate of end use products produced by the seven corn dry mills with daily capacities of 30,000 bu/day or more.

From: R. J. Alexander. 1987. Corn Dry Milling: Processes, Products and Applications. In: Corn Chemistry and Technology. Edited by S. A. Watson and P.E. Ramstad. American Association of Cereal Chemists, Inc., St. Paul, MN.

Table 5. Effect of Drying Air Temperature on Dry Milling Yield of Products Recovered by Rolling and Grading and on Other Factors.

	Drying Air Temperature, °F					
Product	35–60	90	140	190	240	290
Grits, 1st Brk, %	19	14	10	8	7	4
Fat, % db	0.5	0.6	0.6	0.6	0.7	0.8
2nd & 3rd brk, %	28	32	32	33	31	30
Fat, % db	0.8	0.9	0.9	0.8	1.0	0.9
Prime product mix (grits, meal, and flour)	63	62	59	57	54	48
Fat, % db	0.8	0.9	0.8	0.7	0.9	0.9
Recoverable oil, lb/cwt of corn	2.5	2.5	2.5	2.6	2.6	2.6
Stress cracks, %	7	56	68	70	82	84
Ratio multiple to single	0.1	0.8	1.5	1.2	2.1	2.1
Stein CK2, % Breakage susceptibility	3	5	7	14	27	35
Test weight, lb/bu	58.5	56.5	53.0	53.5	53.0	51.5
Germination, %	85	75	23	6	—	—

From: Brekke et al. (1973). Dry milling of corn artifically dried at various temperatures. Transactions of ASAE. 16(4):761-765.

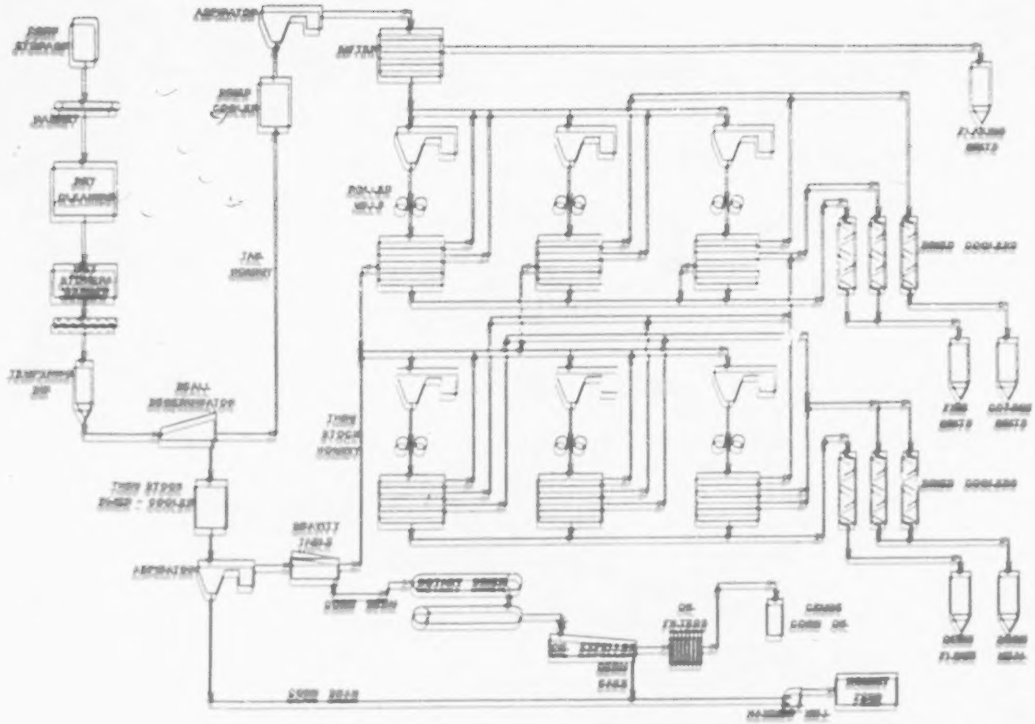
ASPIRATOR
SIFTER
DRY CLEANING
TEMPERING BIN
BEALL DEGERMINATOR
TAIL HOPPER
ROLLER MILLS
THRU STOCK HOPPER
THRU STOCK DRIER - COOLER
ASPIRATOR
GRAVITY TABLE
DRIER COOLERS
DRIER COOLERS
OIL FILTERS
CRUDE CORN OIL
HAMMER MILL

Figure 1. Flow chart for a typical tempering-degermining corn dry milling plant. From: Alexander, R.J. 1987. Corn Dry Milling: Processes, Products, and Applications. In: Corn Chemistry and Technology. Edited by S.A. Watson and P.E. Ramstad. American Association of Cereal Chemists, Inc. St. Paul, MN. p 354.

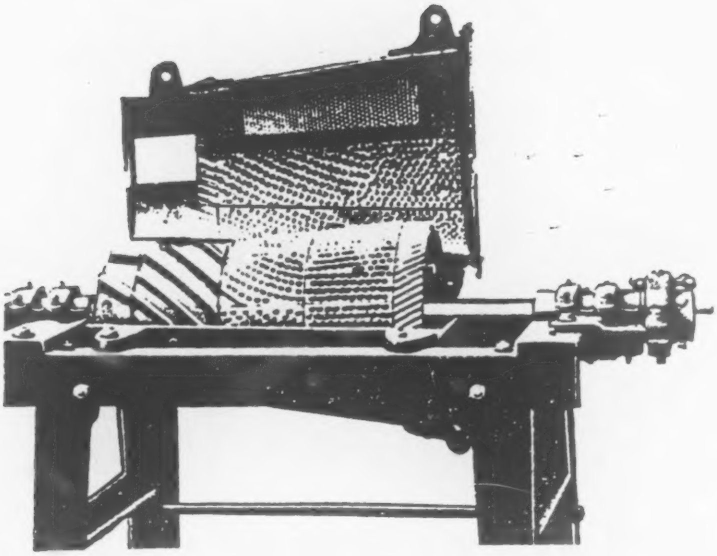

Figure 2. Beall degerminator showing auger intake section (left), knob-like protrusions (center), studded roll at discharge end (right). From: Beall Product Literature. Union Iron Works. Decatur, IL.

Background Paper No. 10

Grain Attributes for the Feed Industry

Tilden W. Perry
Purdue University

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Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Enhancing the Quality of U.S. Grain for International Trade." The views expressed are those of the author(s) and not necessarily those of OTA.

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CHAPTER 1

INTRODUCTION AND CURRENT STATUS OF THE FEED INDUSTRY

In 1985, analysts of the USDA Economic Research Service sent more than 8,300 survey questionnaires to all known feed establishments in the United States. Feed mills included in the survey had to (1) be involved in grinding and mixing at least two feed ingredients and (2) have a normal weekly production capacity of 25 tons or more (summarized in Feedstuffs, Reference Issue, July 29, 1987).

The above analysts found the U.S. feed manufacturers have undergone some adjustment since the 1970's, probably in response to several changes in the various livestock sectors. The number of feed mills had declined 16% (7,900 in 1970 to 6,600 in 1984). Moreover, the production per mill had increased 4% going from 16,500 tons per year in 1975 to 17,200 tons per year in 1984.

Formula feed production was centered heavily in the Corn Belt, Southern Plains, Southeast and Lake States. Although larger mills with an annual capacity of 75,000 tons or more comprised only about 5% of the total number of mills, yet such mills produced almost 30% of the total annual production of the nation.

Corporations dominated the ownership of the feed mixing faculities, accounting for 58% of such establishments and 68% of formula feed production in 1984. Farmer cooperatives comprised nearly 29% of the U.S. feed mills and 24% of the total tonnage.

Types of Feed Manufacturers

Primary feed is defined as that which is mixed from individual ingredients, sometimes with the addition of a premix at a rate of less than 100 lb per ton of complete feed. U.S. feed manufacturers produced about 98 million tons of primary feed in 1986 in contrast to 101 million tons in 1981, representing a slight (3%) but even decline over the last five years. Primary feed may be a complete feed, or it may be a supplement, concentrate or other feed product that will be mixed with additional ingredients before feeding. Approximately 90% of the production of the feed industry is primary feed.

Secondary feed is that which is mixed with one or more ingredients plus a formula feed supplement (which is a primary feed), the latter of which normally is included at a rate of 300 pounds or more per ton of finished feed, depending upon the protein, calcium and phosphorus density desired in the finished feed.

Feed concentrates, defined as feed grains, wheat, rye, oilseed meals, animal protein feeds and other byproduct feed ingredients, fed in 1986 were up about 1% from the previous year to 209 million tons. In addition, it was estimated about 100 million tons of feed concentrates were mixed or fed free choice by livestock feeders on their own premises. Although primary feed tonnage has been fairly constant for several years, the use of feed concentrates has climbed. For example, the use of feed concentrates had increased 16% between 1983 and 1986.

Species utilization of manufactured feeds was led by broilers (22%), followed by beef and sheep (19%), dairy (19%), starter/grower/layer/breeder chickens (14%), swine (13%), turkeys (6%) and others (7%).

Type and Quantity of Raw Materials Used

Feed grains

Swine consume approximately 32% of the corn, sorghum, oats and barley (table 1-1) fed to animals, followed by beef cattle (28%), dairy cattle (20%) and poultry (18%).

Table 1-1. Consumption of Feed Grains by Type of Livestock - 1985

	Corn, sorghum, oats and barley	Wheat, rye
	---------- million tons ----------	
Dairy animals	29.6	1.0
Cattle on feed	32.9	3.1
Other beef cattle	7.3	1.2
Hens, pullets, chickens raised	8.8	.4
Broilers	13.8	.8
Turkeys	3.5	.6
Hogs	46.8	1.2
Other livestock and unallocated	1.2	8.6

USDA Economic Res. Serv., FdS-298, 1985.

Byproducts

Byproduct feedstuffs represent a critical aspect of the feed industry, especially for providing supplemental protein. In 1986, 41 million tons of byproduct ingredients were utilized in the feed industry.

High protein

a. *Oilseed meals* are of plant origin resulting from the production of various oils. It is estimated 22 million tons of high-protein oilseed meals were utilized, of which 92% was soybean meal. The oilseed meals represented 53% of the grand total of byproduct feeds for feed manufacture. Thus, soybean meal represented nearly one-half (48.7%) of the grand total of byproducts utilized in animal feed formulations.

b. Animal proteins, including tankage and meat scrap, fish meal and solubles and milk byproducts, constituted about 7.6% of the total byproduct feeds, with tankage and meat scrap representing 84% of this category.

c. Grain protein feeds consist of gluten feed and meal, brewer's dried grains and distillers dried grains. The total of all this category of these medium proteinaceous grain feeds represents about 7.5% of the grand total of byproducts that are incorporated into feedstuffs.

d. Other byproducts, including wheat millfeeds, rice millfeeds, dried and molasses beet pulp, alfalfa meal, fats and oils, molasses and miscellaneous, make up another 31% of the byproducts going into animal feeds.

CHAPTER II

DESCRIPTION OF RAW MATERIAL

Types of Raw Materials

Feed Grains Average characteristics of the principal feed grains are set forth in table 2-1. It should be borne in mind that almost any biological material will vary in composition among samples. For example, the protein content of corn dry matter may be as low as eight percent and as high as 11 percent, for a range of approximately 30 percent. Generally, the grains will not vary as much in composition as is true for forages and straws and for grain manufacturing byproducts.

Many factors affect the variations in grain analyses that one may encounter, including genetic varieties, soil fertility, rainfall, and length and type of storage, in the case of the carotenes and xanthophyl. Variations in grain analyses will affect their analysis - and thus their economic value. Therefore, it is critical that at least limited analyses of grain be made, including crude protein.

The feed grains as a class are characterized as high energy grains, due to their relatively high levels of nitrogen-free-extract (principally starch) and low levels of crude fiber, except for oats grains. Nearly all of the feed grains are highly palatable to livestock when they are free of contaminants, such as dust, mold, or rodent excreta. Rye is the only feed grain that is sometimes less acceptable by livestock. Corn is the leader in the amount of energy contained, followed in declining order by wheat and barley and milo.

Oats, with their fibrous cover ~~are~~ considerably higher in crude fiber than the other feed grains, and thus contain less available energy.

Corn is the lowest of all the feed grains in protein content, but the protein of all the feed grains has a relatively low biological value for monogastric animals, due to the deficiency of one or more essential amino acids. Therefore, in formulating diets for swine and poultry, care must be taken to utilize sources of supplemental protein which will add sufficient amino acids to balance those deficient in the feed grains. Corn consumption, by specie, in the U.S. is shown in Table 2-2.

Table 2-1. Characteristics of feed grain.[a]

Item	Corn	Sorghum (Milo)	Oats	Barley	Wheat	Rye
	Analysis, dry matter basis, %					
Protein	10.2	12.2	13.2	13.0	14.3	18.5
Crude fiber	2.3	2.5	11.9	6.0	2.8	5.1
Ether extract	4.6	3.2	5.1	1.9	2.9	3.7
Nitrogen-free-extract	81.4	80.1	66.0	75.7	78.1	68.5
Ash	1.5	2.0	3.8	3.4	1.9	4.2
Total digestible nutrients						
Cattle	91.2	80.2	74.5	80.8	85.0	74.8
Swine	92.2	86.7	69.7	70.8	91.1	81.9
Calcium	.02	.03	.10	.08	.11	.08
Phosphorus	.32	.31	.37	.45	.45	.71

[a] Crampton and Harris, 1971.

Table 2-2. Corn consumption by kind of livestock in the USA.[a]

Type of livestock	Year, million metric tons			
	1970	1975	1980	1985
Dairy animals	12.8	13.5	16.8	20.7
Beef cattle on feed	22.0	19.2	17.8	20.0
Other beef cattle	5.6	5.6	5.7	4.8
Hens, pullets, chickens raised......	9.1	7.9	9.9	6.6
Broilers (chickens)	6.0	5.2	9.8	11.9
Turkeys	1.5	1.5	2.4	2.9
Swine	33.2	27.2	38.0	39.8
Other (unallocated)	1.1	1.1	2.6	1.8
All livestock and poultry	91.3	81.2	103.0	108.5

[a] United States Department of Agriculture, Economic Research Service, Washington, D.C., FdS-298, Dec. 1985.

All the feed grains are extremely low in calcium content (.02 to 11%) and it is important that such deficiencies be taken into account in formulating livestock diets. The feed grains are not rich in phosphorus, although barley, wheat, and rye contain considerably more phosphorus than corn, sorghum, and oats. In addition, the availability of the phosphorus contained in the feed grains may not be greater than 50 to 75%, to monogastric animals, due to the phytin contain. Phytin tends to chelate the phosphorus contained in the feed grains, making it unavailable to pigs and poultry.

None of the feed grains contain any appreciable amount of vitamin D, and only yellow corn contains pro-vitamin A (beta carotene). Farm animals are able to convert pro-vitamin A into active vitamin A in varying quantities. For example, apparently the Holstein can convert more provitamin A into active vitamin A, than is true for the Guernsey cow. Thus, one of the reasons Guernsey milk has a more characteristic yellow color than is true for Holstein milk is that the Guernsey cow secretes much of her dietary pro-vitamin A (yellow) directly into the milk, unchanged. Similarly, fattening beef cattle should receive vitamin A _per se_, in their diet or else they may actually develop a borderline vitamin A deficiency (Perry, et al., 1966).

High Protein Oil Meals Characteristics of the principal high protein oil seed meals are contained in Table 2-3.

Table 2-3. Characteristics of the high protein oil meals.[a]

Item	Soybean meal (49)	Cottonseed meal	Linseed meal	Peanut meal	Sunflower meal
	Analysis, dry matter basis, %				
Protein	52.4	44.7	39.4	51.8	46.8
Crude fiber	5.9	11.8	9.7	14.3	11.6
Ether extract	1.3	6.0	5.6	1.3	3.1
Nitrogen-free-extract	33.6	30.9	39.1	27.7	26.7
Ash	6.6	6.6	6.2	4.9	8.3
Total digestible nutrients					
Cattle	82.4	79.4	80.7	76.8	65.2
Swine	85.0	--	76.5	64.5	73.5
Calcium	.33	.20	.43	.22	.46
Phosphorus	.73	1.18	.95	.71	1.12
Amino acids					
Lysine	3.43	1.59	1.32	2.51	3.36
Methionine	.67	.56	.71	.44	1.68
Tryptophan	.66	.52	.61	.47	1.12

[a] Crampton and Harris, 1971.

This category of feed ingredients is relatively high in protein (39 to 52%, dry matter basis). However, since normally lysine tends to be the first limiting amino acid in monogastric diets, either soybean meal or sunflower meal lead the rest in that category. In fact, with either methionine or tryptophan as the second limiting amino acid encountered in formulating swine and poultry diets, dehulled sunflower meal is highest of all the high protein oil meals, in all three of the first limiting amino acids.

The oil meals all are much higher in calcium than the feed grains, and contain at least twice the phosphorus attributed to the feed grains. Normally, feed formulators apply approximately a 50 to 75% availability factor to oil meal phosphorus - as in the case of the feed grains - due to the presence of phytin which tends to chelate the phosphorus contained, making it not as available. However, dehulled sunflower meal contains 13% less energy for swine and 20% less energy for beef cattle, than soybean meal. The soybean meal consumption by specie is shown in Table 2-4.

Grain Protein Feeds. This group represents several products which are byproducts of grain processes which produce products for human consumption. Characteristics of some of these are listed in Table 2-5.

Table 2-4. Soybean meal consumption in the USA, by species of animal.[a]

Specie	Soybean meal consumption, million metric tons 1970	1975	1980	1985
Dairy cattle	1.0	1.6	1.5	1.7
Beef cattle on feed	0.9	1.2	0.6	0.9
Other beef cattle	0.6	0.7	0.8	0.8
Hens, pullets and chickens raised	2.2	2.7	2.6	1.9
Broiler chickens	1.9	2.4	3.3	4.1
Turkeys	0.8	1.0	1.3	1.8
Swine	4.3	5.1	4.9	5.2
Other livestock	0.5	0.5	0.6	1.8
All livestock and poultry	12.2	15.2	15.6	18.2

[a] United States Department of Agriculture, Economic Research Service, FdS-298, 2985.

Table 2-5. Characteristics of the grain protein feeds.[a]

Item	Analysis, dry matter basis, %			
	Corn gluten feed	Corn gluten meal	Brewer's dried grains	Distiller's dried grains
Protein	25.8	43.0	27.9	29.7
Ash	7.3	3.6	4.8	2.4
Crude fiber	8.1	5.1	11.7	13.4
Ether extract	2.9	2.6	7.4	9.9
Nitrogen-free-extract	53.2	45.9	47.9	44.7
Total digestible nutrients				
Cattle	81.9	82.8	73.0	84.3
Swine	88.5	87.6	69.4	98.7
Calcium	.49	.16	.30	.10
Phosphorus	.86	.51	.66	.18
Amino acids				
Lysine	.88	.82	.90	.91
Methionine	.33	1.10	.60	.48
Tryptophan	.22	.23	.40	.22

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[a] Crampton and Harris, 1971.

The grain protein feeds, much of which are byproducts from corn utilized in the manufacture of fructose, starch and alcoholic beverages, contain medium levels of protein (26-29%).
Corn gluten meal is the exception, and contains 43% protein. Since all of these products are derived from the feed grains, the balance of essential amino acids contained in the protein is not very good. Most of the xanthophyl of the corn (brilliant yellow color) is concentrated in the gluten fraction. Therefore, even though the balance of essential amino acids in corn gluten meal is not very desirable, gluten normally is included in broiler and laying hen diets to impart the highly desirable yellow color to broiler meat and to laying hens' legs, beak and eye skin.

Because of their bulky nature, both corn gluten feed and brewer's dried grains are desirable in dairy grain mixes.

Miscellaneous Byproduct Feeds. Several wheat byproducts exemplify this category best, and include such as wheat bran (14.8% protein, 10% fiber), wheat middlings (17.7% protein, -7% fiber), wheat shorts (16.8% protein, 8.2% fiber) and wheat germ meal (25% protein, 3.5% fiber). Most of these products are utilized in dairy grain mixes because their higher fiber content and poorer balance of essential amino acids make such materials less desirable as a constituent in most poultry and swine diet. An exception to this is that wheat bran often is included in the diet of brood sows, late in gestation, because wheat bran tends to have a laxative effect on animals.

Physical Quality Characteristics

Corn, wheat, and soybeans normally are harvested in the whole grain form. It has been said that "nature" realized the value of a compact pelleted product in protecting the germ contained until such time as it found itself in warm, moist, fertile soil. Therefore, the undamaged grain is actually fairly well protected, at least for quite awhile. Many grains may actually contain a protective waxy coating or covering which gives it some added protection. However, once the protective coating is damaged, many forms of destruction of the grains will ensue. These types of damages will be discussed in a later section. The remainder of this section will be devoted to how the physical alterations of corn, wheat, and soybeans - and of their byproducts - affect their feeding value.

Grinding. One of the earliest techniques of altering the physical characteristics of grains was to grind them - initially with large and heavy sections of rocks. More sophisticated hammer mills, roller mills, and burr mills are capable of breaking the grains, currently.

What are the advantages of decreasing the physical size and shape of grains? First of all it is necessary to achieve considerable reduction in particle size of the grains in order to achieve a homogeneous mixture that will not segregate in transport. Furthermore, there are varying digestive capabilities associated with whole vs. ground or cracked grains. Although the digestibility of corn is not affected greatly by grinding, for most species of animals, whole wheat is quite another matter. Therefore, it is imperative that wheat be ground or cracked for optimum utilization for most farm animal situations. In contrast, care must be utilized in the preparation of any of the feedgrains to prevent too find grinding (powdery to the touch). Feedstuffs which are ground too finely are excessively dusty and are not relished as well as feedstuff that is not ground so finely; dusty feed may irritate the eyes and respiratory tract of animals.

Cooking. It is most imperative that either soybean seeds or the resulting solvent extracted meal thereof, be cooked to approximately 225°F, for monogastric animals. Cooking of soybeans or of soybean meal performs several benefits - (a) destroys the trypsin inhibitor contained in raw soybeans, (b) makes the sulfur-containing amino acids (methionine and cystine) more available, (c) destroys the bitter taste characteristic of raw soybeans, and (d) destroys the urease present.

Almost any method of heat treatment of corn (roasting, steam, flaking, micronizing) will improve its nutritional value for cattle and sheep, but cooking of corn does not improve its feeding value for monogastrics (pigs and poultry). This difference in response to cooking by ruminant vs. monogastric animals is not explainable currently.

Several methods for cooking grains are described as follows (Ensminger and Olentine, 1978).

1. Dry heat processing.
   a. Roasting is a process of heating feed to a desired temperature of approximately 275°F (135°C). Research conducted by the author demonstrated roasted corn was more digestible than non-roasted corn. In the roasting

process, the whole grains are tumbled through an open flame in a revolving drum.

b. Micronizing is a coined word used to describe a dry heat treatment of grain by microwaves emitted from infrared burners. The grain is heated to 300°F (149°C) by infrared burners as it passes along an oscillating steel plate.

c. Popping is the exploding or puffing out of grain resulting from the rapid application of dry heat. This is the same principle as processing popcorn for people. The principle is based on the use of superhot dry heat with the grain heated to 300° to 310°F (149° to 154°C), preferably with grain containing 15 to 20% moisture, to enhance the explosion effect.

2. Moist heat processing.

a. Steamflaking is the most common method of moist heat processing of grains. This process differs from steam rolling or crimping in that the grain is subjected to steam under atmospheric conditions for from 15 to 30 minutes prior to rolling. Large heavy mill rollers set at near zero tolerance produce a very thin flat flake. The flaking process results in gelatinization of the starch granules, rendering them more digestible.

Intrinsic Characteristics Critical to End Product.

Most of the factors which will be discussed in this section relate to things which lower the nutritional value - and thus the economic value of corn, wheat, soybeans or their byproducts. In other words, corn, wheat, and soybeans, and byproducts therefrom, which are produced, handled and stored under optimal conditions are considered to be the epitomy of most desirable products for use in the manufacture of formula feeds. Any quality attribute less than this will detract from the nutritional and/or sale value of such materials. Several factors, alone or in combination, which will lower the feeding value of corn, wheat, soybeans and their products are discussed briefly.

Moisture. First of all, water is weight, and must be paid for in transportation costs, and possibly in sale cost. Furthermore, water reduces bulk density so that will occupy more space per unit dry matter than drier grain. Damp grain flows less readily in loading and unloading procedures, thus making such procedures more time-consuming and bothersome and thus more expensive.

Official grain standards have been established by the United States Department of Agriculture (1985) which specify what the maximum levels of moisture may be in the various grains, *i.e.*,

Grade designation	Maximum moisture content	
	Corn	Soybeans
U.S. No. 1	14.0	13
U.S. No. 2	15.5	14
U.S. No. 3	17.5	16
U.S. No. 4	20.0	18

Increased moisture content need not detract from the animal nutritional value of the grains (corn, wheat) if they are stored under limited-oxygen conditions. In fact, ensiled higher moisture corn has a greater available energy value for beef cattle, per unit of dry matter, than U.S. No. 2 corn (15.5% moisture).

One of the most important considerations of the moisture content of grain, as related to its potential value, is that deterioration of grain in storage tends to be related directly to its moisture content unless oxygen is excluded from such products. The rates of growth and development of microorganisms, insects and mites, as well as the rate of which chemical and physical changes take place, will increase greatly with increased levels of grain moisture content. However, feedstuffs can safely contain more moisture if the temperature of the product is lowered and uniform (no fluctuations) throughout. If, however, there are differences in temperature in parts of the storage area, moisture will move from a warmer area to a cooler area. Therefore, temperature gradients in stored grain may tend to decrease its nutritional value ultimately.

Microflora. Fungi are a major cause of spoilage in stored grains and seeds, and probably rank very high in the order of things which deteriorate and detract from the nutritional as well as processing qualities of corn, wheat, soybeans and their byproducts.

Several species of Aspergillus, Penicillum, Alternaria, Dreschslera, Fusarium and Phoma are reported to infect the feed grains and soybeans during storage (Salunkhe et al., 1985). Moisture content and temperature are the primary factors which affect the development of storage fungi in grains. A moisture level above 12 to 13% with warm air favors fungal growth.

Several types of damage result in feed grains as the result of the growth of microflora, including:

(1) Decrease in germinability. This topic will be cited, but not developed to any degree since this paper is designed to evaluate products destined for the feeding of livestocks.

(2) Discoloration. Both field and storage fungi may cause discoloration of whole seeds or of portions of them, particularly the germ and embryo. In accordance with the Official Grain Standards of the United States (USDA, 1964), "Damaged kernels shall be kernels and pieces of kernels of corn which are heat damaged, sprouted, frosted, badly ground damaged, badly weather damaged, moldy, diseased, or otherwise materially damaged." Except for sprouted and frosted kernels, most of the above involve varying degrees of discoloration of the kernels. Wheat in storage, for example, oftentimes develops very dark germs and then is identified as "germ damaged" or sick wheat. Such germs are high in fatty acids and also are exceptionally friable. According to the evidence of Christensen (1955) it is quite probable that germ invasion by fungi in storage is the major contributing factor to this condition.

(3) Heating. At one time it was assumed the respiration of moist grain itself was responsible, chiefly, for the heating that often accompanies spoilage. However, Hummel et al. (1954) reported that respiration of wheat free of storage fungi, with moisture contents of 14 to 18%, and kept at 35°C, was so minimal that it was not detectable. The evidence by Christensen and Gordon (1948) indicates microflora are responsible, primarily, for the heating of moist grains.

Heat loss damage can be estimated by a formula suggested by Salunkhe et al. (1985). This involves counting and weighing moldy grains separately:

$$\text{Percent weight loss} = \frac{(Und) - (DNu)}{U(Nd + Nu)} \times 100$$

where U = weight of undamaged grains; Nu = number of undamaged grains; D = weight of damaged grains; and Nd = number of damaged grains.

Heating can be prevented by (a) controlling moisture level to below 14%, (b) controlling or excluding oxygen, as in ensiling, or (c) maintaining environmental temperature at 20° or lower.

Walker (1967) delineated the steps in spontaneous combustion as follows. When the moisture content of stored grains is sufficiently high, *aspergillus restrictions* and *A. glaucus* can grow. The latter will grow sufficiently rapidly that it can cause an increase in temperature of up to 40°C. Once the moisture content of grain exceeds 15.5%, *A. candidus* can grow; at 18.5% moisture, *A. flavus* can grow. When both *A. candidus* and *A. flavus* are growing, the temperature can rise 55°C. So a combination of moisture and of fungi is operating to cause a heating effect.

Several aspects of excessive heating of the feed products are worthy of consideration. Naturally, the production of heat requires a source of energy and most likely this will come first from the most available carbohydrates. Thus, grain that has been through such a heating process will contain less available energy as a feedstuff. Even more critical with proteinaceous products, such as soybean meal, wheat middlings, corngluten meal, etc., higher heating will cause a "carmelizing" effect. This effect can cause a destruction of the protein and amino acids.

(4) Mustiness, caking and total decay. These are the final stages of spoilage caused by fungi, when the organisms involved become detectable by the unaided eye, and possibly also by the unaided nose.

(5) Mycotoxins. These are metabolic products produced by the fungi. Such products have been of great concern since about 1961 when aflatoxin, the first mycotoxin of known economic importance to be identified and characterized, was shown to have been responsible for the death of large numbers of poultry in England. More than 150 species of fungi have been reported from cereal grains (Christensen and Kaufman, 1969). However, Christensen (1965) points out there are close to one hundred thousand different kinds of fungi, and that such are not rare, but are present throughout the world.

Insects and mites. Insects cause significant losses in stored grains. The USDA (1965) estimated a loss of .5% of all grain stored for 12 months due to insect damage. Insect damage has been classified under four general categories (Salunkhe et al., 1985):

a. Insects feeding primarily within the grains, viz. granary weevil and Angoumois moth.

b. Insects feeding on both grain and cereal products, viz. cadelle beetle and grain borer.

c. Insects feeding on cereal products, viz. confused flour beetle, saw-toothed lgrain beetle, flat grain beetle, Indian meal moth, Mediterranean moth, rice moth and mites.

d. Insects straying in milling machinery or in cereal products but not ordinarily considered mill pests, viz. insects attracted by artificial light such as black carpet beetle, silver fish and springtail.

Insect infestations result in contamination by entire insects or parts thereof. Infestations may include eggs, egg shells, larvae, pupae, cocoons and mature insects. Internal-feeding weevils deposit their feces inside the kernels.

A variety of treatments are available to control insect infestation, including acceptable insecticides, fumigants, certain plant products and even irradiation. However, specifics will not be attempted here because use of insecticides on materials intended for feed and food would have to be administered by trained and licensed personnel.

The USDA Grain Inspection Handbook (1985) lists strict standards as to the number of insects that can be found in representative samples of grain. Under those standards, 500 gm of grain shall be taken for each 2000 bushels (50 metric tons) of grain. Corn, for example, is "considered weevily" if the 500-gm sample contains two mor more live weevils, or one live weevil and five or more other insects injurious to stored grain, or fifteen or more live insects injurious to stored grain.

Rodents. The economic impact of rodents upon feed grains is twofold, namely, (1) contamination, and (2) consumption. Dykstra (1966) gives an illustration of what would happen if one rat were left in a wheat storage place for just 365 days. During that time it would consume approximately 27 pounds of wheat, and deposit 25,000 dropings weighing between two and four pounds. In another dramatic description of the effect of rodents on the world supply of food, Dykstra (1968) "it would take one train 2,800 miles long (more than 1/10 of the World's circumference) to carry the grain India's rats consume each year."

Of serious concern, in addition to the quantity of grain consumed by rodents, a considerable amount of that not consumed is contaminated with rodent urine, excreta, hair, and extraneous debris such as carried-in nesting material. An undue proportion of the expense of flour milling must be devoted to screeing, washing, scouring, aspirating and otherwise cleaning the grain before it enters the break rolls.

The USDA Grain Inspection Handbook (1985) specifies the taking of a 1000-1050 gm sample cut from a representative sample. Ten or more rodent pellets, bird droppings or an equivalent amount of other filth shall cause that batch of grain to be graded U.S. Sample grade.

Foreign Material. Almost anything that does not belong in feed grains can be classified as foreign material. However, the main focus here is on such things as weed seeds, dirt, debris, broken kernels (in whole grain). A category known as BCFM is identified as "broken corn and foreign material." In corn grading this is characterized as any materials that will pass through a 12/64 inch round hole seive, plus any material - other than corn - that remains on the seive. The same is specified for wheat, and for other feed grains. For example, No. 1 corn is defined as having 56 lb. minimum weight per measured bushel, a maximum of 2% foreign material, a maximum of 3% damaged kernels, and a meximum of 0.1% heat damaged kernels.

The basis for determination of "foreign material" is the examination of 1000 to 1050 gm of grain cut from a representative sample (USDA, 1985). Foreign material includes sticks, stones, weed seeds, pieces of glass, pieces of metal and any nondescript substance which is not typical of the grain. This category includes broken seeds, also.

Characteristics That Influence Production Efficiency

Properly balanced diets containing wholesome ingredients are necessary for most efficient livestock production. Anything less than that will result in less than optimal production efficiency. This section will deal with characteristics of diets built around some combination of corn, wheat, soybeans, or byproducts therefrom which might alter production efficiency.

Foreign Material. Any foreign material in feed ingredients is undesirable merely from the standpoint that such materials will serve as a diluent. In addition, foreign material may be potentially injurious. For example, bits of metal such as nails, short pieces of wire, feed tag fasteners, screws, bolts, and small pieces of sheet metal generally will sink to the bottom of a cow's rumen and remain there. Sharp pieces of metal may actually pierce the rumen wall, producing a semi-permanent, nonhealing wound. Ruminant animals which accumulate excessive amounts of metal in their rumen will develop a deterioration in their health characteristic of a condition known as "hardware disease."

Other foreign materials such as ground corn cobs, beeswing, dust and dirt, and weed seeds, all of which have greatly lessened nutritional value for animals, will lessen the economic value of any feedstuff in which they are contained.

Excessive amounts of dust in feeds presents another hazard that is great concern to the feed manufacturing trade. This is the hazard of a potential dust explosion which has destroyed many a feed milling operation.

Too Finely Ground or Processed. In addition to the potential for dust explosions, referred to above, extremely dusty feedstuffs (powdery to the touch) present additional potential hazards. Very dusty materials which carry potent drugs, for example, may tend to lodge in the elbows of pipes or in corners of storage places, but break loose later and perhaps contaminate another batch of feed.

Dusty feeds may affect the acceptability of such by livestock. Sheep and cattle do not relish dusty feeds, whereas this is not such a problem for either swine or poultry.

Oftentimes an edible oil or fat is added to feed formulations which are too dusty. On example of a naturally dusty feedstuff is solvent extracted soybean meal, which contains less than one percent of fat. Therefore, incorporation of solvent extracted soybean meal into a formulation will increase any tendency for dustiness of the total diet.

Cooking or Heating. Under certain conditions the cooking or heating of feedstuffs will improve the production efficiency. Soybean meal is such an example. The cooking of soybean protein to a higher temperature (280°F +) will help to make it more nearly a "by-pass" protein, which is beneficial to ruminant animals.

The cooking of corn (roasting, steam flaking, micronizing, popping, etc.) will improve its nutritive value approximately 10% for beef cattle.

Pelleting. In the case of corn, wheat and soybeans, pelleting has not improved the nutrient value appreciably. In the case of fibrous grains, such as barley, pelleting has improved nutrient value for swine. Furthermore, the pelleting of broiler diets, then crumbling of same before feeding, has improved broiler performance somewhat.

Moistening or Slopping. Research has shown there is no nutritional advantage for slopping or diet moistening for hogs. However, much research has demonstrated that the ensiling of corn containing about 25% moisture - either natural or reconstituted obtained by adding water to dry corn - will improve the utilization of the corn dry matter by cattle approximately ten percent.

Weathering, Molding, and Miscellaneous Damaging. Anything which will damage the feed grains such as weathering will decrease the feeding value of such grains dramatically. In addition, the passage of time will decrease rapidly the provitamin A potential (beta carotene) of yellow corn. Smith et al. (1963) demonstrated that whereas one-year old corn contained adequate pro-vitamin A for liver vitamin A storage, corn which had been in storage for four years and did not afford nearly as much liver storage of vitamin A for pigs consuming it.

CHAPTER III

PROCESS DESCRIPTION

Soybeans

Since soybean oil has been utilized as a separate entity, the majority of soybeans utilized in the feed industry are extracted of their oil content, with the residual being toasted and ground.

Soybeans first are generally cracked by means of corrugated rolls. Next in the processing line is the dehuller. Some processors dehull soybeans prior to pressing. When dehulling is practiced, the dehulling equipment usually consists of a combination of air and screen separation. The hulls thus may be drawn off between the first and second pairs of cracking rolls by air suction, then passed over a screen to remove any portions of the seeds that have been removed by the hulls. Such seed portions fall back into the material stream whereas the soybean hulls are transported by air or conveyor to a grinder. These hulls may be kept separate or eventually they may be recombined with the extracted meal stream.

Moisture content of the cracked soybeans must be reduced. The cracked soybeans are heated to about 140°F and then proceed through a series of rollers where they are flaked. Following a cooling period, to about 115°F, then the flakes are exposed to continuous extraction with hexane, which extracts the oil down to less than .5% remaining in the bean flakes. The extracted flakes are transported to driers held at a temperature of 208°F for approximately 10 minutes, to drive off any residual hexane. From the drier, the flakes are transported to the toaster for a 90 minute toasting treatment at 220°F. Following the toasting, approximately 10 to 20 minutes are required in the aerator-cooler to drop the temperature of the flakes to 100°F. After cooling, the flakes are moved to the grinder for reduction to the ultimate soybean meal-sized product.

Although there are methods of separating the oil (approximately 18%) of soybeans from the non-oil portion other than by the solvent method, today practically all processed soybeans utilize the solvent extraction method. Prior to the perfection of the solvent-extraction method, soybeans were processed by either the hydraulic or expeller methods which employed a pressure technique. Soybean meal processed by either the hydraulic or expeller system contained approximately 5% oil.

Corn

The major end products in corn processing range all the way from fructose sweetner to ethanol to liquor. It is estimated, though, there are more than 100 industrial and food uses for corn. However, the major end products are derived primarily from the more than 65% of starch (dry matterbasis) contained corn. Most of the corn processing goes through what is known as the wet milling process.

After a cleaning process, the corn is steeped in a series of tanks where a relatively weak solution of sulfurous acid loosens the hull. This 28 to 40 hour process also helps break the protein-starch band which exists within the corn kernel.

The steeping water, separated from the kernels, contains 5 to 6% solids, of which more than 35% is corn protein, most of which is zein. The first spin-off product, then, is the corn "steep water", which is condensed by evaporation to near 50% solids. This product can be used in livestock feed as an extender for cane molasses. An alternate use is to combine it with gluten and hulls to produce corngluten feed.

From the steeping tanks, the softened kernels go through the degerming mills which breaks apart the kernel, and the germ is separated from the rest of the material in passing through a liquid cyclone. Thus, a second portion, the germ containing nearly all of the oil, but less than 4% of the total corn, is separated out and utilized for the production of corn and corngerm meal.

With the removal of the solids in the steep water, plus the corngerm, there now remains the starch, gluten and hulls. This mixture is ground finely in specially cutting mills and washed through a series of reels and shakers. The reels are large revolving tubes made of nylon stretched over frames. The starch and gluten are washed through the nylon, but the hulls are too coarse to get through and ultimately are collected separately. Finally, the starch and gluten are in a process which employs their difference in density, and thus since starch is heavier, it sinks to the bottom.

Wheat

Brownish bran layers cover the outside of the wheat kernel; the bran contains most of the protein and the minerals of the wheat kernel. Under the bran layers is the brownish aleurone layer, which also is rich in protein. The germ, located at one end, contains almost all of the oil, plus some protein and minerals. The remainder of the kernel consists of thin-walled cells packed with starch grains, but particles of gluten can be found among the starch gains.

Cleaned wheat is moistened first to toughen the bran, then it is passed between pairs of steel rolls, the first pair of which are corrugated. The rolling process gradually breaks down the kernel into pieces, flattens the bran and separates the flour from the bran. The flour is removed from this mixture by sieves and bolting cloth. Further down the production line, the various byproducts are separated out, and all possible flour is recovered at each step of the separating process.

Wheat Bran. This product is derived from the coarse outer coating of the wheat kernel. It is highly palatable and has a mile laxative effect. It has 16% protein and not more than 10% fiber. It supplies 70% total digestible nutrient.

Wheat Middlings. This may contain some particles of bran. It contains more protein than bran, but the quality of protein is not very high. Total digestible nutrient content is 77%.

CHAPTER IV

MAJOR TECHNOLOGICAL IMPROVEMENTS IN THE FEED INDUSTRY WITHIN THE PAST DECADE

Changes in Raw Materials That Have Generated Technology Changes.

Raw materials have changed very little in the past decade. Over a longer period of time such genetic developments as high-lysine corn and starchy corn came upon the scene, giving feed grain producers and users additional options. In other words, plant breeders have produced new varieties and seed characteristics but, with the adoption of genetic engineering capabilities, it is proposed rather drastic changes in grain characteristics can be anticipated. The impact of such changes in grain attributes cannot be predicted at this time except to suggest their presence must be acknowledged.

A few observations which may affect the technology of the industry may be worthy of note.

By-Pass Protein for Beef Cattle is a new concept that could have a great effect on the feed industry. Research at Purdue University (unpublished data) has shown that a combination of urea and hydrolyzed poultry feathermeal is superior to soybean meal as a source of supplemental protein. Furthermore, the costg of the combination of urea and feathermeal required is less than one-third that of the cost of soybean meal to supply the same amount of protein. Because of America's increasing consumption of poultry meat (70 pounds per capita per year), poultry feathers are in great surplus. Based upon today's estimates of soybean meal consumed by animals (USDA, 1985), more than 18% of all soybean meal utilized by animals is fed to beef and dairy cattle (3.4 million metric tons of 18.2 million metric tons, total). This new technology could be adopted rather quicly and would have two effects on the feed industry, namely, (1) adapting to utilize hydrolyzed feathermeal and (2) being faced with an extra amount (10 to 12%, or more) of soybean meal.

Although the author and other researchers have known of the potential for both hydrolyzed feathermeal and urea in beef cattle nutrition, the role of by-pass protein has become known only relatively recently. Therefore, it was possible to achieve the results listed in the first paragraph by combining feathermeal (by-pass protein for breakdown and absorption from the intestine) and urea (for breakdown in the rumen to provide nitrogen for ruminal bacteria).

European Economic Community (EEC) indication of intent to ban the importation of dry corn gluten feed caused considerable uneasiness among corn processors. The EEC has been an important market for this byproduct of starch and ethanol production. Any move in this direction could have a strong impact on the feed industry.

Changes in Feed Feed Technology That Have Generated Advancements in Raw Material Characteristics.

Little if any changes have occurred in the past decade. In other words, most feed ingredients have essentially the same characteristics typical of them in the 1970's.

Relationship Between Raw Material Characteristics and Technological Advancements in the Feed Industry.

Naturally the feed industry must be ready to adapt to any new characteristics of the raw materials it utilizes. For example, when the use of monensin in cattle feeds was permitted by the Food and Drug Administration, feed mixers who produced cattle supplements had to get their whole mixing program in compliance. No such factor has come along in the past decade, however.

CHAPTER V

NEW OR EMERGING TECHNOLOGICAL AREAS

Products Being Produced

This is an area where reasonable prediction plus considerable dreaming can take place.

Genetic Engineering. It is anticipated many new products will be produced by genetic engineering of seedstock in the immediate decade or two. For example, a higher protein corn could have a marked effect upon the amount of supplemental protein feed manufacturers would need to supply livestock feeders.

Perhaps mold resistance can be engineered into raw materials; perhaps insect resistance can be incorporated into raw materials.

Synthetic Amino Acids. As synthetic amino acids become more abundant at an economical price, greater use of them will be made in animal feed formulation. This can have an impact on the quantity of protein supplements that are utilized in feed formulation.

Impacts on Raw Material Characteristics. All animal nutrition is based upon optimal balance of the essential nutrients, as best we understand such needs. Thus, a higher protein corn would result in lower supplemental protein needs to be supplied by the feed manufacturer. Greater use of synthetic amino acids would decrease the tonnage of oil meals and animal protein products in the formula feed industry.

Even though scientists may change the characteristics of raw materials and even though research may more accurately define and re-assess animal nutrient needs, feed manufacturers will adapt to meet such needs. Feedstuffs represent from 50 to 75% of the total cost of a livestock enterprise. Feed manufacturers will adapt their machinery and manufacturing capabilities to meet such needs because there is a tremendous economic opportunity for them in doing so.

SUMMARY

Feed manufacturing output per year has tended to follow the size of the livestock industry. More recently there has been a rapid surge in the amount of poultry meat and the numbers of eggs produced in the U.S., thus the production of poultry feed has reflected that change in the animal industry. One trend in livestock production has tended to negate the correlation between livestock numbers and manufactured feed tonnage. As swine and beef feedlot units have become larger, the management of such units has become a purchaser of individual feed ingredients which are mixed on site at such units. Thus, when feed manufacturing tonnage figures are presented, it might first appear the total number of livestock on feed has declined.

Corn, wheat and soybean by-products are feed ingredients discussed in this presentation. Corn is an energy source because of its high starch content. However, several by-products from the utilization of corn in food manufacturing processes are available and include such products as corn gluten feed and corn gluten meal, principally. Wheat is an excellent ingredient for livestock formulations but, because of the need for flour, several by-products are available, including wheat bran and wheat middlings. Soybeans are a high protein (38%)-high oil (18%) seed. However, the high value for soybean oil does not allow for much entry of whole (ground) soybeans into the feed manufacturing industry. Rather, the by-product of the soybean oil industry - soybean meal - is the most important contribution of soybeans to the feed industry.

Corn or wheat, grown, harvested and stored under optimal conditions, are excellent feedstuffs for livestock. Furthermore, the by-products of corn, wheat or soybeans, when processed (including toasting for soybean meal) and stored properly, are excellent feedstuffs. Therefore, feedstuff quality factors which affect the feeding value of these products will be discussed in light of factors which cause such products to have less than optimal feeding value.

Naturally, the safety of feed ingredients is of the highest concern to feed manufacturers. Any aspect of feed ingredients which would make such less than safe would detract from the desirability of such products. The presence of any fungi or microflora would always present a threat to the safety of such products. Therefore, more than minimal contamination by molds of any sort would lower the potential feeding value of such (gibberellin-infested corn will be rejected by swine). Although moisture content per se is not a detriment to the potential feeding value, yet the propensity for molds to grow and proliferate often is related to the level of moisture present. Furthermore, the level of moisture is inversely related to the percent of dry matter contained.

Perhaps second to microflora as a danger, or threat of animal toxicity, is the presence of either rodent excrement or pieces of dead animals. There is quite a potential for the transport of diseases since rodents can be carriers for animal diseases. In addition to the potential for diseases, etc., from rodents, there is considerable loss in quality of nutrients in feed ingredients since rodents tend to consume the highly energetic starch and germ portions, leaving the lower energy bran.

Following the above two toxic aspects of feedstuffs, which decrease their feeding value, would be anything that results in a diminution of the feeding value. It is not practical to rank these in decreasing order of importance because the degree of diminution of feeding value affects its potential for decreased value. Nevertheless, several factors fall under this category. Mustiness, caking and decay are high on this list and represent not only a loss in feeding value but also a loss of dry matter nutrient. In addition, many animals reject feedstuffs damaged in this manner and will not consume such.

Feedstuffs which have gone through an excessive heating process in storage - possibly even approaching spontaneous combustion - may have the protein contained either partially or totally denatured so that it has lost its specificity for monogastric animals. Such heated feedstuffs often may be off-color, also.

Presence of insects or mites represents less than optimal feeding value. Such insects and mites will consume feedstuffs and, in turn, deposit fecal material which detracts from the palatability of the feed materials.

Presence of foreign materials causes a dilution of feedstuffs with materials that have very little feeding value. Examples of foreign materials found in feedstuffs include pieces of corn cobs, dirt, seed hulls, weed seeds, small pieces of metal and small pieces of wood. Generally these products are not potentially dangerous to animals - except possibly for metal fragments - but they will dilute the quality of feedstuffs as well as present problems to feed manufacturers and processors.

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Background Paper No. 11

Technology for the Inspection of Corn, Soybeans and Wheat

Charles R. Hurburgh
Iowa State University

March 1989

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Enhancing the Quality of U.S. Grain for International Trade." The views expressed are those of the author(s) and not necessarily those of OTA.

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of
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1. THE U.S. GRAIN INSPECTION SYSTEM

Grain is inspected every time it changes hands in the market place. As demonstrated by the flow chart in the introduction to this study, some marketing chains involve many trades and therefore many inspections. In addition, there may be several internal inspections--for warehouse certification, internal quality control, etc. Hill (1988) presents a detailed account of inspection authority and its application. In the U.S. system, there certainly is no shortage of opportunities to determine grain quality and to reflect preferences for particular quality attributes. This flexibility in some ways is a hindrance to quality because the interchangeability required to sustain multiple trading options can be incompatible with specific users' individualized quality needs.

The U.S. Grades and Standards Act provides the current universal language of grain quality. By amendment in 1976, the Act requires Official inspection by government personnel representing the Federal Grain Inspection Service (FGIS) on all export shipments. Regulations supporting the Act establish procedures for Official inspections. For any domestic trade, the use of Official inspection is voluntary at the request of either trading party. Domestic inspections are done under the authorization of FGIS by a delegated state or a designated agency. Delegated states are state governments authorized by FGIS to perform all Official inspections within that state. Designated agencies are private contractors authorized by FGIS to perform Official inspections within an established territory. Grain inspection is a user-fee supported service.

In practice, most trades between elevators, especially in the export market chain, involve an Official grade. Using an Official Grade establishes the testing methodology and sets a third party as the judge of quality. However, some end users and nearly all country elevators purchase on "house grades," testing done by their own personnel. House grades are also often used when a company is shipping grain between two of its own facilities. House grade inspections generally measure the same factors as are in Official grades, except in cases in which a particular buyer has some special criteria for quality (e.g., corn endosperm hardness for dry milling). House grade equipment and procedures are regulated only to the extent that the individual states choose to do so. The number of factors measured in a house grade inspection is strictly at the discretion of the buyer. So the U.S. Grades set the format but not necessarily the practice for domestic inspections.

Inspection can partly determine shipment routings. For example, a consistent discrepancy in moisture tests between two buyers can affect their relative business volume. Local markets, with less standardization of testing procedures, are subject to more variability in results. Testing discrepancies can cause sellers to "grade shop," to look for the most favorable test. Some inspection variability is unavoidable, but deliberate differences intended to either attract sellers or protect buyer interests should be eliminated. Testing differences and, therefore, grade shopping are less likely to occur in Official inspections than in house grade inspections. However, the report Commitment to Quality (NAEGA, 1986) identified one such problem in the Official system--Grade established from probe sampling of barges relative to Grades from mechanical diverter sampling.

A disturbing trend is developing in export sales--the use of an independent, commercial inspector to establish quality for payment, thus superceding the FGIS inspection. This trend was obvious in a review of recent export contracts (Huffman, 1987). Both Taiwan and the USSR require independent analysis or observation to verify FGIS results. By law, FGIS grades must be used to load vessels, except for factors not certified in the Official system. So buyers insisting on duplicate testing are in effect, expressing distrust of the U.S. national inspection system. This trend is not to be confused with buyers requesting additional analyses not performed in the Official system.

Of equal concern is the apparent dichotomy of USDA supporting the Official system but not requiring its application on grain forfeited or stored under farm-support-program provisions. Under the U.S. farm policy, growers have the right to forfeit grain to the USDA in exchange for forgiving the loan they received earlier. The grain was collateral for the loan and becomes property of USDA. It is then put into storage or released. Because house grades can be used to measure quality of forfeited grain, inconsistencies can occur. In the long run, intermarket inconsistency lowers the incentive to retain quality and assures that a lower-grade product will be exported.

2. TERMS AND PROCEDURES FOR INSPECTIONS

2.1. Types of Grade Certificates.

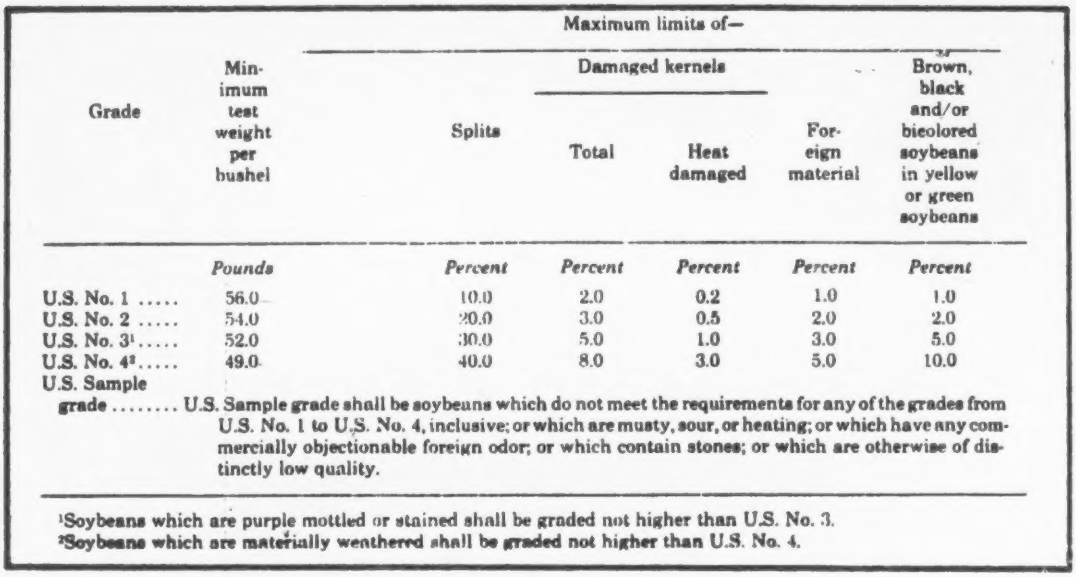
There are three types of Official certificates, denoted by their color. White certificates mean that the inspector drew the sample and performed the analysis. Pink or submitted sample certificates mean that the inspector had no control over sampling. Yellow certificates mean that a licensed warehouse inspector drew the sample. White certificates have an official FGIS logo ghosted on them. All Official certificates, white, pink, or yellow, will list values for applicable factors, plus the Official grade designation. White certificates generally are considered more reliable. It was the view of Grain Quality Workshop participants that grain covered by white certificates often trades at a premium over that with pink certificates. The essence of certificate differentiation is that the test results are no better than the samples used to obtain them.

2.2. Grade Factors and Their Designation

The grading tables for corn, soybeans, and wheat are reproduced from FGIS procedures in Tables 2-1, 2-2, and 2-3. Grade factors fall into one of three designations: grade-determining, special, and Official criterion. Grade-determining factors appear in the numeric grade line (e.g., test weight, damage, etc). Their values establish numeric grade, with the worst factor being determining. Factors such as odor (commercially objectionable foreign odor, COFO), stones, etc., make grain sample grade (the lowest grade) regardless of the levels of the other factors.

Grade	Minimum test weight per bushel	Maximum limits of— Broken corn and foreign material	Maximum limits of— Damaged kernels Total	Maximum limits of— Damaged kernels Heat-damaged kernels
	Pounds	Percent	Percent	Percent
U.S. No. 1	56.0	2.0	3.0	0.1
U.S. No. 2	54.0	3.0	5.0	.2
U.S. No. 3	52.0	4.0	7.0	.5
U.S. No. 4	49.0	5.0	10.0	1.0
U.S. No. 5	46.0	7.0	15.0	3.0
U.S. Sample grade	U.S. Sample grade shall be corn which does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; or which contains stones; or which is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.			

Table 2-1. Grades and grade requirements for corn (USDA, 1980a)



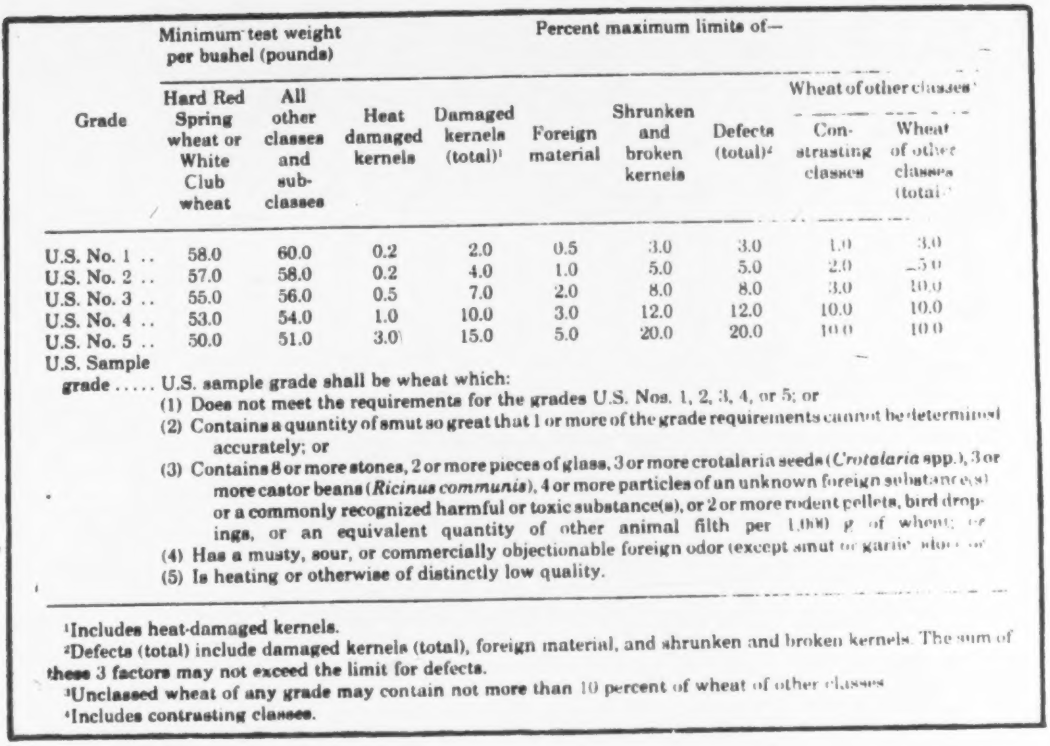
Grade	Minimum test weight per bushel	Maximum limits of—				
		Splits	Damaged kernels		Foreign material	Brown, black and/or bicolored soybeans in yellow or green soybeans
			Total	Heat damaged		
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
U.S. No. 1	56.0	10.0	2.0	0.2	1.0	1.0
U.S. No. 2	54.0	20.0	3.0	0.5	2.0	2.0
U.S. No. 3[1]	52.0	30.0	5.0	1.0	3.0	5.0
U.S. No. 4[2]	49.0	40.0	8.0	3.0	5.0	10.0
U.S. Sample grade	U.S. Sample grade shall be soybeans which do not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 4, inclusive; or which are musty, sour, or heating; or which have any commercially objectionable foreign odor; or which contain stones; or which are otherwise of distinctly low quality.					

---

[1] Soybeans which are purple mottled or stained shall be graded not higher than U.S. No. 3.

[2] Soybeans which are materially weathered shall be graded not higher than U.S. No. 4.

Table 2-2. Grades and grade requirements for soybeans. (USDA, 1980b)



Grade	Minimum test weight per bushel (pounds)		Percent maximum limits of—						
	Hard Red Spring wheat or White Club wheat	All other classes and sub-classes	Heat damaged kernels	Damaged kernels (total)[1]	Foreign material	Shrunken and broken kernels	Defects (total)[4]	Wheat of other classes[3]	
								Con-strasting classes	Wheat of other classes (total)[4]
U.S. No. 1 ..	58.0	60.0	0.2	2.0	0.5	3.0	3.0	1.0	3.0
U.S. No. 2 ..	57.0	58.0	0.2	4.0	1.0	5.0	5.0	2.0	5.0
U.S. No. 3 ..	55.0	56.0	0.5	7.0	2.0	8.0	8.0	3.0	10.0
U.S. No. 4 ..	53.0	54.0	1.0	10.0	3.0	12.0	12.0	10.0	10.0
U.S. No. 5 ..	50.0	51.0	3.0	15.0	5.0	20.0	20.0	10.0	10.0

U.S. Sample grade ..... U.S. sample grade shall be wheat which:

(1) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

(2) Contains a quantity of smut so great that 1 or more of the grade requirements cannot be determined accurately; or

(3) Contains 8 or more stones, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 3 or more castor beans (*Ricinus communis*), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), or 2 or more rodent pellets, bird droppings, or an equivalent quantity of other animal filth per 1,000 g of wheat; or

(4) Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor) or

(5) Is heating or otherwise of distinctly low quality.

---

[1] Includes heat-damaged kernels.

[2] Defects (total) include damaged kernels (total), foreign material, and shrunken and broken kernels. The sum of these 3 factors may not exceed the limit for defects.

[3] Unclassed wheat of any grade may contain not more than 10 percent of wheat of other classes

[4] Includes contrasting classes.

Table 2-3.. Grades and grade requirements for wheat. (USDA, 1980c)

Special grade factors attach an additional grade statement in addition to the numeric grade. "Waxy" corn is a special grade designation documenting the presence of corn with high amylose properties. "Infested" is assigned as a special grade when the tolerance limits for live insects are exceeded.

Official criteria are factors that do not affect the grade designation but that FGIS has the capability to measure. Moisture in all grains and dockage in small grains are examples of Official criteria. These two are in the Standards and, thus, mandatory. They must be measured and listed on all Official certificates. Official criteria can also be optional; wheat protein, for example. The optional Official criterion is the model recommended for the introduction of end-user related factors into Official inspections (NAEGA, 1986)

The exact procedure and order of testing is established by FGIS (USDA, 1980a,b,c). Refer to the appropriate chapter of FGIS procedures for more description. Any user of Official inspection is entitled to three review inspections to question the original result -- 1) a field review by the agency doing the original inspection, 2) a field office review by FGIS supervisory personnel, and 3) an appeal to the Board of Appeals and Review in Kansas City. In each case, the review inspection result replaces the original result. Board appeals are final. Appeal inspections are done on the file sample divided out before the original inspection unless a resampling is requested and can be done. Thus, appeals are subject to variability of subdivision and/or resampling as well as differences in analysis.

2.3. Concepts of Standardization

The term standardized means that a measuring device has been adjusted to be in fundamental agreement with a universally accepted standard and that ongoing efforts are made to keep it in agreement. Standardization is vital to fair trade; it will be even more important as technologically advanced testing equipment is used by the market place. Probably the most visible example of standardization is the scale program coordinated by National Bureau of Standards, an agency of the U.S. Department of Commerce. Tolerances are established for deviations of scales from known weights; agencies responsible for weight certification (FGIS among them) follow NBS procedures in performing periodic checktesting (NBS, 1988a). NBS Handbook 44 forms the nucleus for many measuring instrument standardizations such as weight, length, volume, and time. National Bureau of Standards coordinates development of measuring standards and instrument calibration procedures.

For grain measures other than weight, FGIS maintains its own standardization program for Official inspections. NBS has also been working on moisture-meter certification. Handbook 44 contains some procedures that can be used by individual states to inspect house-grade equipment (NBS, 1988b). All new NBS methods must, before inclusion in Handbook 44, be approved by the National Conference on Weights and Measures, an association of state weights and measures officials to which FGIS is only an advisory member. Improvement of the interrelationship between FGIS and NBS will be necessary for true national standardization of grain testing.

2.3.1. Reference methods and traceability

The validity of a commercial measure is judged by comparison with another more stringent method accepted as determining the "true" value. For dimensional measures such as mass, time, and volume, the reference standards are very precise. The procedure of matching routine devices against working standards and working standards against the primary standards introduces little variability.

Some terminology is useful in describing standards. The primarily reference or primary standard is the base method defined as being the true value. A secondary standard is another method proved to agree with the primary standard but simpler to use. For example, the air-oven method is a secondary standard for moisture to the Karl Fischer titration method. A working standard is the device and method used to actually validate an individual test instrument. It may or may not be the primary or secondary standard method. Moisture meters are often checked by comparison with another meter (working standard) that has been calibrated against the oven (secondary standard). The chain between instrument and primary standard is called traceability.

The more steps in the traceability chain, the more chances for compounding ("stacking") random errors one atop the other. Some comparisons are more precise (lower standard deviation) than others (e.g., two moisture meters vs. a meter and the oven). Minimizing the number of comparison steps in the traceability chain may or may not maximize accuracy, depending on the actual size of random variations.

Grain quality measures are difficult to standardize because the "true" answer often is not known; for example, moisture content. So the reference method is defined rather than proven. Using grain samples to calibrate instruments introduces sampling variation independent of the analytical errors. The reference methods can also be as variable as the instruments, as again is true for moisture content (Hart and Neustadt, 1957).

2.3.2. Calibration

A standard instrument is calibrated to match either a primary or secondary reference method. This is essentially a statistical problem; many statistics texts describe least-squares methods that can be used for instrument calibration. The major calibration issue in grain quality testing is the pervasive variability of these tests. Both the instruments to be calibrated and the reference methods are subject to error. Changes in grain properties because of climatic variables complicate the problem of locating a truly representative sample set. Calibration requires a two-step process; development on one sample set, followed by validation (prediction) on an independent sample set.

Several statistics are useful in describing calibration performance:

1) R^2, the percentage of sums of square deviations from the mean explained by the calibration equations.
2) SEC, standard error of calibration, equal to the square root of the mean square error in the calibration equation.
3) SEP or SEE, standard error of prediction (estimation), the standard deviation of errors relative to the reference, for the prediction (or other independent) sample set.

No one statistic is sufficient, although overuse is made of R^2. Low R^2 (less than 90%) does not necessarily mean poor fit, particularly if the sample set is diverse and fully representative. High R^2 may be an indication of overselection of "good" data. Furthermore, the larger the range in values, the more easily a high R^2 can be achieved. Correlation coefficient, the square root of R^2, is sometimes reported. This leads to confusion because the correlation coefficient values are always closer to 1.0 than the equivalent R^2 values. All three statistics should be cited to support a given instrument calibration. SEP has the most relevance in practice because it quantifies the uncertainty of future test data.

Hurburgh et al. (1987) developed a general variance model to analyze instrument errors relative to a standard.

$$(2\text{-}1)\quad V_t = V_{ss} + V_y + \frac{V_i}{m_i} + \frac{V_r}{m_r}$$

Where:

V_t = total variance (mean square error of the prediction set) relative to reference

V_{ss} = sample-to-sample component of V_t. Differences in grain sample properties within a year.

V_y = year-to-year component of V_t. Influence of climate.

V_i = variance among replicates of the instrument. Often called the precision of the instrument, includes subsampling of replicates.

V_r = variance among replicates of the reference

m_i, m_r = number of replicates

The terms can be further subdivided if desired (e.g., to separate regional effects in V_{ss}). It is presumed that the instrument is accurate; that is, there is no statistically significant systematic discrepancy (bias) from the reference. If bias exists, it must be mathematically removed before applying eq. (2-1).

Expected error tolerances are related to eq. 1 as:

(2-2) $T = \pm 2 \left(\frac{V_t}{N}\right)^{1/2}$

where:

T = expected error range of the instrument ($P = 0.05$)

N = number of samples in the prediction set

Equations (2-1) and (2-2) can be applied to calibration check studies, regulatory programs, and establishment of reasonable trading increments. More effective use of statistical data would resolve many debates over testing accuracy. The key point, however, is that a diverse sample set may be needed if V_{ss} and V_y are large. Diversity requires time and effort; in regulatory activities, answers often are demanded before the data are available to provide them. As an example, V_{ss} and V_y were 53% and 35% of V_t, respectively, for moisture meters in corn (Hurburgh et al. 1987).

There are several pitfalls to avoid. The variance components are often functions of quality level, which violates the independence assumption of least-squares regression. The data can be divided into increments to calculate variances as a function of level. The SEC (from the initial calibration equation) will underestimate variability and should not be used as an estimate of $V_t^{1/2}$.

2.3.3. Sampling error versus analytical error.

Separation of errors into those associated with analysis and those associated with sampling may seem to be a fine point. However, sampling plays a key role in quality testing; certain factors are more prone to sampling error as opposed to analytical error (Hurburgh and Bern, 1983; Hurburgh, 1984). Mathematically, sampling error is modelled by further dividing V_{ss}, V_i, and V_r into sampling and analytical components. V_{ss} contains essentially all the sampling error except subdivision of replicate from a small sample. Knowledge of the relative importance of components is crucial to prevent resources being wasted on sampling vs. analytical errors of little practical consequence. Improving moisture meter precision (repeatability) is an example of unnecessary effort because it contributes less than 10% of total variability (Hurburgh et al., 1987). Moisture measurement errors arise mainly from differences in electrical properties of grain samples, not from the precision of the meter to measure electrical properties. When examining variability of any test made with an instrument, it is essential to know the relative contribution of instrument error.

Likewise, omission of certain sources of error from an analysis will cause inflated expectations of performance or disruptions in trade. The calculation of SEP (Woodall, 1986) for evaluating the cu-sum shiploading plan is an example. Several components of sampling error (the errors of the diverter sampler and sample subdivision down to the representative portion) contributing to V_{SS} were left out (W. Woodall, 1987, personal communication) which means that sampling-oriented factors (primarily particle-size factors) may have their SEP's underestimated. The components were omitted because the data base available to calculate variability did not capture those components. A more complete explanation of loading plans is in section 3-8.

3. METHODS OF MEASUREMENT

This section describes the methodology for measuring important grain quality factors. Not all are in the current U.S. Grades and Official criteria. For each factor, the following items are discussed: current practice, standardization and accuracy, identified problems, potential new technologies, and assessment of needs.

3.1 Moisture Content

3.1.1. Current practice

Moisture content is nearly always measured in trade with a capacitance-cell electronic moisture meter. Electrical capacitance at high frequency (20 mhz - 2.45 ghz) increases nearly linearly with moisture content (Nelson, 1978). Figure 3-1 shows this relationship. Bulk density and sample temperature also affect capacitance (Nelson, 1981). Moisture meters used for trade generally have a means of correcting readings for variations in both.

There are four major brands of meters used for trade - Steinlite, Burrows, Dickey-john, and Motomco. All Official inspections are made with Motomco 919 meters. A Motomco meter is shown in Figure 3-2. A complete description of each brand is given in Hurburgh et al. (1985). Trade-type meters generally test about

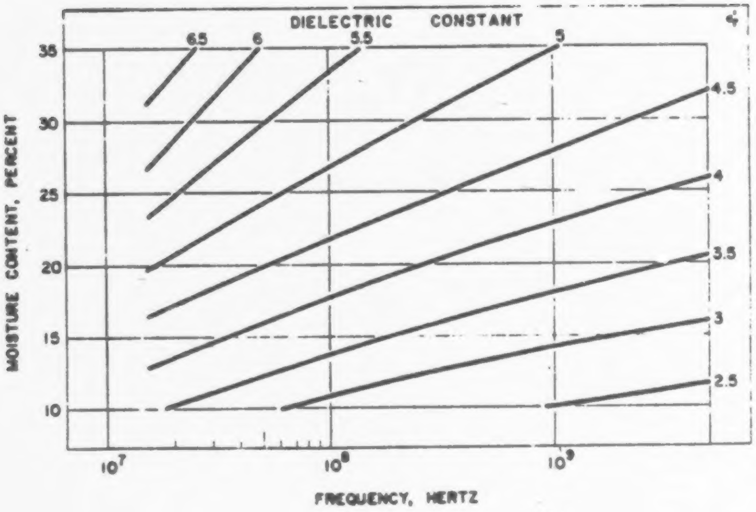


Figure 3-1. Relationship of dielectric constant to moisture content in corn. (ASAE, 1987)

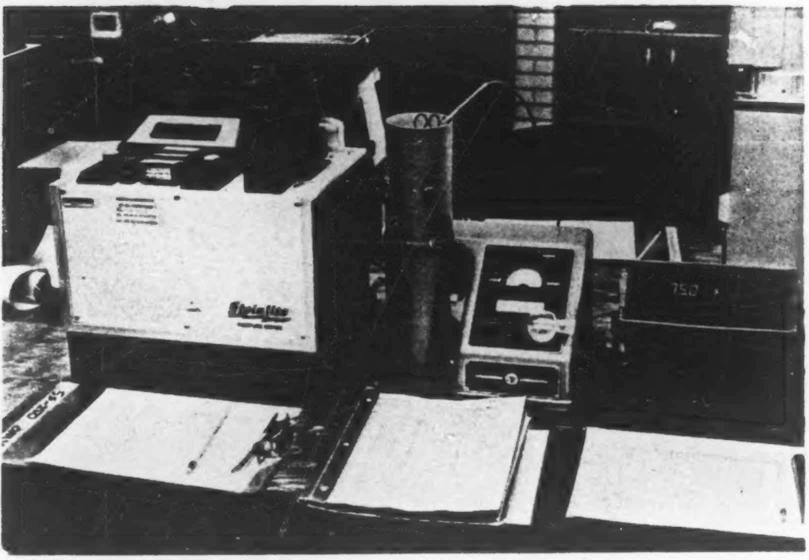


Figure 3-2. Steinlite (l) and Motomco (r) moisture meters.

250 g of grain. The sample weight must be known so the meter either has internal weighing (Dickey-john) or requires a preweighed sample (all others).

Farmers use smaller, less expensive models of capacitance-cell meters. There are more brands of farm-type meters and relative market shares of each are hard to estimate. Farm-type meters, normally require more operator activity (manual temperature corrections, look-up conversion charts, etc.) than do trade-type meters (Hurburgh et al., 1986).

Several other measurement principles are used on a limited basis. Air relative humidity is related to moisture via the equilibrium moisture content (EMC) property. However, relative humidity sensors are imprecise (± 5%), and the EMC at a given humidity varies by ± 1% among samples of corn, wheat, or soybeans. Electrical resistance is well correlated with moisture content up to 22-23% (corn). Resistance meters have had problems measuring wet corn accurately (Zeleny and Hunt, 1962). Microwave absorption is a promising technology that is now used in milling to measure moisture of freshly tempered grain. Near-infrared reflectance (NIR) and transmittance (NIT) are sensitive to moisture (Massie and Norris, 1965). There have been many reports of NIR measuring moisture in various products to an SEP of 0.4 percentage points or less.

3.1.2. Accuracy and standardization

The four brands of trade-type meters are statistically accurate in corn compared with the USDA whole-grain oven method if the Iowa-Illinois calibrations are used (Hurburgh et al., 1987). These calibrations are so-named for the two states that developed them. The current FGIS calibrations for the Motomco are part of the Iowa-Illinois calibrations. In states that do not enforce accuracy or that allow other sets of calibrations, certain trade type meters will test up to 1.0-1.25 percentage points higher than the oven and the Motomco (Hurburgh et al., 1985). In soybeans, Motomco and Dickey-john agree with the oven, Steinlite reads higher (Hurburgh, 1987a).

The published data underscore the need for national standardization of test equipment. FGIS updates calibrations for Motomco every three years (USDA, 1986). The Grain Quality Workshops established the principle that all meters in all inspections and on farms should be calibrated to agree with Official inspection results (NAEGA, 1986). Iowa and Illinois researchers have established that oven methods are repeatable between laboratories to within 0.25 percentage points. Therefore, there is no technological reason that meters cannot be made to agree with each other. FGIS monitors accuracy of its meters with wheat samples and by tracking comparisons among individual meters through the Grain Inspection Monitoring Service (GIMS) database.

Iowa and Illinois use a meter-to-meter matching procedure. Wheat samples are less subject to changes in environment or condition and pack more uniformly in the meter cell. Meter matching is useful for on-site inspections because the comparison of two meters is subject to about 50% less random variation than the comparison of a meter and the oven.

Other states use oven-pretested samples. Pretested samples do not work for inspecting large numbers of meters (e.g., the 2500 meters used for trade in Iowa) because they change moisture with use (Martin and Schwarberg, 1980). Tolerances must be so wide as to not be discriminatory. The purpose of on-site checking is to identify defective meters, not to validate calibrations. The latter is a laboratory function.

Farm type meters are less accurate than trade meters (Hurburgh et al., 1986). Evidently meter manufacturers do not all maintain standardization to the official reference method. There is no legal requirement that they do so, but erroneous measurements will have serious repercussions in drying and storage.

Variability (SEP) of meters has been studied in recent years. The SEP of trade-type meters at 15% corn moisture is 0.6 points (Hurburgh et al., 1987) and, at 13% soybean moisture, 0.3 points (Hurburgh, 1987a). The SEP of farm-type meters is 1.1 points and 0.4 points, for the same corn and soybean moistures respectively (Hurburgh et al., 1986). SEP's in corn increase with both increasing and decreasing moisture from the optimum 15-19% range. Soybean SEP's hold constant over normal trading ranges. The SEP of trade meters is nearly equal to that predicted from variations in basic capacitance data, which means that whole-grain capacitance technology is nearing the limits of its accuracy and precision. Recent unpublished data by the author show whole-grain near-infrared transmittance may have an SEP equal to or less than that of capacitance meters.

A key issue for moisture measurement is difficulty in choosing a base reference method. All oven methods are empirical, relying on weight loss that is assumed to be water. Varying oven parameters will give varying results (Paynter and Hurburgh, 1983); FGIS has proved that, in corn, the Karl Fischer titration method gives results about 0.7 percent higher than the current whole-grain oven method. Most international buyers use an oven method standardized to the Karl Fischer method and thus feel that the USA is understating moisture. Our current oven methods were originally matched to Karl Fischer (Hart and Neustadt, 1957), but changes in grain properties have altered the relationship. The standard deviation between two reference methods is as great as between a meter and a reference method.

Establishment of the Karl Fischer method as primary standard would require three levels of standardization, Karl Fischer, air-oven, and master Motomco meter. The potential for error-stacking is large.

3.1.3.Problems with moisture measurement

1. There is no accepted world reference method.
2. Grain condition (damage and breakage) affect capacitance moisture-meter readings even though there is no way to compensate for them (Hemeda et al., 1982).
3. Freshly wetted and freshly dried samples do not test accurately in capacitance meters because water is not distributed uniformly in kernels.
4. Current meters sense only average moisture content, not the range among individual kernels.
5. The market trades in 0.1 percent units, which is beyond the SEP of the meters.
6. Intermarket differences exist because standardization does not extend to all house-grade inspections.

3.1.4. New technologies

Microwave energy is preferentially absorbed by polar molecules. Water is the primary polar molecule in grain. Therefore reduction in microwave signal strength across a grain column can be an indicator of moisture content. There is one such device on the market, costing about $11,000.

It is possible to trap the vapors evolving from an oven heating and react them with a water-specific reagent. In this way, the concerns about dry-matter decomposition in oven methods can be resolved. However, the question of whether all water is removed from the product is not answered. The current equipment of this type would not be suited for elevator use but potentially could be used as a secondary reference standard.

The Karl Fischer reference method is considered the most fundamental and true reference standard. With use of electronic burets, the titration reference method can be automated, at a cost of about $10,000. Extraction by methanol, filtration, and pipetting are still manual. If Karl Fischer is to be the primary standard, then its procedure must be simplified for more routine application. A comparison of the Hart and Neustadt (1957) study and the recent FGIS study shows that two reference methods cannot be trusted to stay in agreement over time, especially if one, the oven, is empirical. Thus, it would be better to avoid the secondary standard if possible.

Near-infrared reflectance or transmittance is a sensitive measure of moisture content. Moisture shows strong absorbance peaks at 1940 mm, among other wavelengths. Section 3.5. discusses near-infrared technology in more detail. At the moment, near infrared is most useful for ground materials, not whole grain. However new transmittance technology holds promise for whole-grain sensing of moisture and other properties. Transmittance of near-infrared light is better suited to whole grains than is reflectance because shape and surface area irregularities cause much variability in the amount and angle of reflected light.

Recent data show that single-kernel moisture can be measured to about ± 1.0% by capacitance and resistance. Finney and Norris (1978) reported an SEP of about 2.0 points using near-infrared transmittance on single corn kernels. There is one resistance meter being prepared for the U.S. market. The single-kernel device probably is the most important new moisture technology. Data on kernel moisture distribution would allow the market to set specifications to control blending and preserve storability. Kernel moisture testing would also be a major aid to grain dryer design in that moisture uniformity could be measured rather than computed by simulation. Kernel moisture distribution may explain storability differences among grain lots ostensibly at the same average moisture content.

3.1.5. Assessment of needs

The reference method issue must be resolved. This is as much an international question as a domestic one. It is a public research topic because only government can establish legal standards. USDA laboratories should have the support necessary to advance this work. The objective should be an essentially similar reference procedure for all grains and an international agreement on these procedures. About $400,000 per year (2 scientists plus support) will be needed. Failure to resolve this issue will result, at some time in the future, a recurrence of moisture complaints.

Single-kernel moisture data will need interpretation. Equipment development will come from the private sector, but interpretation of data will not be simple. How, for example, will one prove that blending rather than natural variation is the source for a given distribution of moistures? How will aeration affect moisture distribution? What distribution is unsafe for storage at what points in the market chain? The research would be best done by laboratories close to various handling operations. Obviously, coordination would be needed. Single-kernel data would be a good subject for the North Central Regional Grain Quality Project NC-151. A total support pool of $500,000 would solve the problem, assuming that the universities contributed faculty time.

Application of spectrometric tests will occur naturally as a consequence of compositional testing. Therefore, no special effort directly related to moisture is needed.

There does not seem a great need for reducing SEP's of moisture measurement in grain trading. Sample mixing and averaging of test results reduce the effect of meter variations. Where single test results must stand alone, the market has accepted and incorporated moisture test error into pricing practices. The uniformity between FGIS and non-FGIS inspections must be improved. There is much greater consequence than from meter variability. All segments of the grain industry have endorsed national standardization, but only government can enforce it.

3.2. Particle-Size Factors.

The Standards for every grain identify, by particle size, undesirable materials. Two sizes, one for small or broken grains and one for fine unidentifiable material, are included. The fine material is combined with large nongrain pieces remaining in the whole grain to make either foreign material (FM) or dockage. The difference is in connotation; FM is grade-determining with tolerances. Dockage is listed on the grade line but is not grade-determining. Usually the market considers dockage to be weight-deductible in that a percentage of gross weight is deducted for each extra 1% of dockage. Coarse grains usually have FM while small-grains have dockage and perhaps FM also.

3.2.1. Current practice

Particle-size separation is done by screening and handsorting (of large pieces). The FGIS grain inspection handbook (USDA, 1980a,b,c) gives detailed procedures for official inspections. A Carter Dockage Tester machine (Figure 3-3) is used in all Official inspections. It is a pass-through cleaner with one eccentric vertical vibrating screen, two sliding screens, a coarse-material screen, and an aspiration fan. Therefore, the Carter machine will make up to five separations in a single pass. Some small grains require this many simultaneous separations. House graders often use one or more hand-held screens in a stack. Hand screening is not as repeatable as the Carter machine and generally gives lower values of percentage passing through (Watson and Herum, 1986).

Corn

Broken corn is material passing through a 12/64-inch round-hole screen but not a 6/64-inch screen. Foreign material is material passing through the 6/64-inch screen plus all nongrain material (coarse FM) remaining atop the 12/64-inch screen. These definitions are new following the mandate of the 1986 Grain Quality Improvement Act. Broken corn and foreign material are still combined to form the Official Grade determining factor BCFM. FM is listed for information purposes. Market reaction to this separate

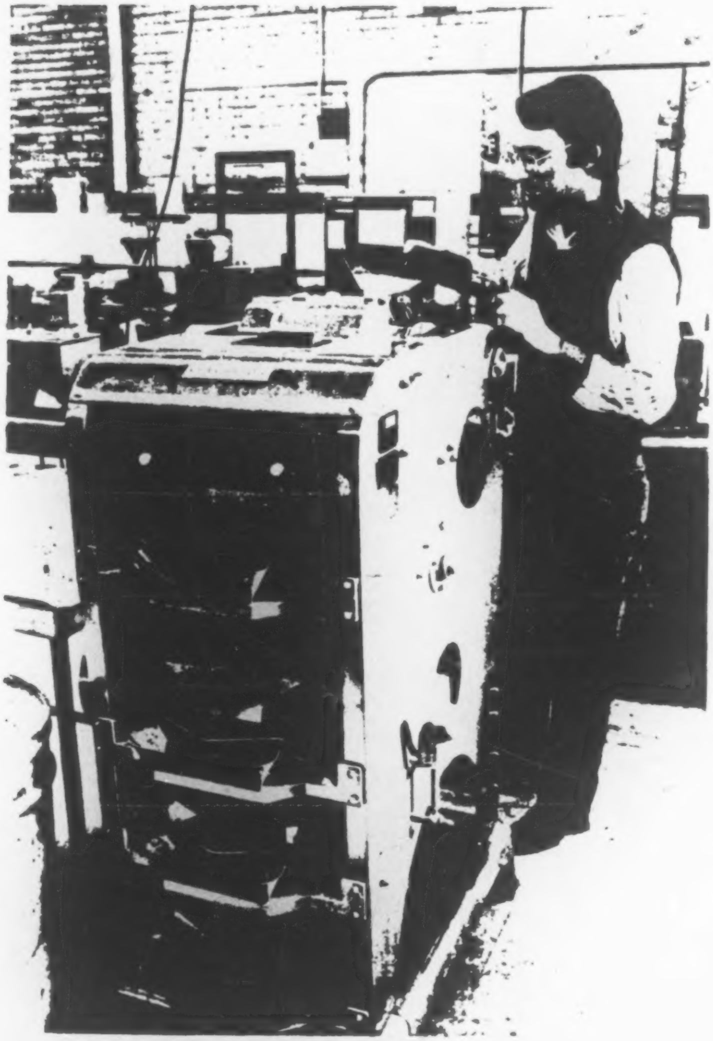


Figure 3-3. Carter Dockage Tester.

listing of FM is not yet available because the special 6/64-inch screens have not been distributed to inspection points. A double screen, 12/64-inch and 6/64-inch, will be used in the top rack of the Carter dockage tester. This was done because the top rack is the only rack with a bouncing rather than horizontal sliding action. The cleaning and blending paper for this study summarized background information on the BC vs. FM issue (Hurburgh, 1988).

Separation of two particle sizes in corn will not present inspection problems. Controlling two sizes in handling a breakage-prone product will be more difficult. Coarse FM, potentially a third particle size, is rarely a problem.

U.S. export corn shipments consistently contain nearly the maximum amount of BCFM for the grade being shipped (USDA, 1987a). Because the export certificate is determined before the final drop into the vessel, a buyer is virtually assured of receiving BCFM in excess of grade limits after unloading. The average increase in BCFM between export certificate and destination unloading is 3-7 percentage points. Depending on use, this may or may not be a problem. However, shipments look dusty. With breakage after certification, there is little incentive for buyers to specify higher grades because the product received will probably be about the same in BCFM regardless of contract grade.

On the other hand, farmer-delivered corn, especially wet corn, rarely exceeds US No. 2 levels (Hurburgh and Moechnig, 1984). Therefore country elevators, in the interest of speed, usually do not measure BCFM.

Soybeans

Soybean foreign material is material passing through an 8/64-inch round-hole screen plus nongrain material remaining atop the 8/64-inch screen. Unthreshed pods must be shelled, with only the pod weight counting toward FM.

Soybean splits are beans with 25% or more broken off. Splits are determined with the aid of a 10/64-inch x 3/4-inch slot sieve, but the inspector must manually remove small beans and coarse FM from the material passing this sieve. Furthermore, not all split beans will pass the slot screen, so the inspector must also check the whole beans for splits. Soybean splits are a time-consuming factor to measure. Country elevators usually measure FM but not splits.

There have been no published studies describing the composition of soybeans by particle size. However, it is accepted in the grain industry that most soybean FM is dirt, weed seeds, stems, etc., with little processing value. FM increases are in the order of 0.5% in vessel loading and unloading (Nicholas and Whitten, 1978). Japanese crushers consistently receive about 0.5% more FM than is shown on Official export certificates (Ishiguro, 1987). This increased FM is likely broken beans.

Export data show that U.S. soybean shipments are consistently close to grade limits for FM (USDA, 1987b). Interior inspections found lower average FM levels, about 1.0% vs. 1.9% at export. The interior trade and domestic processing industry use U.S. No. 1 soybeans as the pricing basis, whereas nearly 80% of U.S. soybean exports in 1986 were U.S. No. 2. Freshly harvested soybeans in the Midwest contain about 0.8-1.0% FM in normal years (Hurburgh et al., 1988). The prevalence of No. 2 grades for export reflects exporter pricing practices intended to allow for handling breakage and inaccuracies in house-grade interior inspections.

Splits percentages do not often approach grade limits either for No. 1 or No. 2 soybeans (USDA, 1987b). Splits do increase in handling, about 2-4% for vessel loading/unloading. The main concern with splits is the tendency for broken beans to increase in free fatty acid (FFA) content (Nicholas and Whitten, 1978).

3.2.2. Accuracy and standardization

Mechanical screening is a relatively precise operation. Carter dockage testers used for Official inspections are periodically check-tested against a master machine in Washington, D.C. Acceptance tolerance is ±0.15 percentage points. Hand screens have a standard deviation among replicates of about 0.2 percentage points. There is no formal procedure for check-testing hand screens used for house-grade inspections.

Sampling error is more important than analytical error in estimating particle-size determination accuracy. Hurburgh and

Bern (1983) reported standard deviations within loads of 1.5 and 1.0 percentage points in probe-sampling corn and soybean truckloads for BCFM (FM in soybeans). When pelican-sampling corn for BCFM, Hurburgh and Moechnig (1984) found a standard deviation of about 0.5 percentage points among truckloads of a supposedly blended lot. Large particle-size variations create the need for multiple probings of trucks, railcars, and barges.

3.2.3. Problems in particle-size analysis

1. Large sampling errors.
2. Segregation and nonuniform distribution.
3. Unclear value difference by particle size.
4. Breakage in handling causing percentages to increase.
5. Slow procedures making expanded testing at country elevators difficult.

3.2.4. New technologies

There are no identified new technologies that would have direct effect on particle-size determination. If several recent proposals (e.g., zero tolerances for corn and soybean FM, government premiums for clean grain) are adopted, there will be pressure for accurate size determination on every load at country elevators. There is no machine that will meet this need. Hand screens are too slow and variable; the Carter Dockage Tester is too slow and expensive. Development of rapid particle-size equipment consistent with Official inspections is crucial for supporting tighter cleanliness standards.

3.2.5. Assessment of needs

The sampling errors and segregation can be alleviated only if the segregatable materials are removed from the grain. Current standards and market practices do not provide the incentives for cleaning to the extent necessary for uniformity. Standards changes must be addressed by public policy makers and market participants. More severe penalties for broken grain will automatically stimulate control of breakage susceptibility and will place breakage susceptibility measurement technology in the marketplace. A very small new discount (e.g., 1 cent per bushel) would provide up to $80,000,000 (corn) in lost revenue that would be available to invest in prevention of further discounts. That is within the range of costs of drying technology that would control breakage susceptibility (Bakker-Arkema, 1988).

The amount of corn FM (6/64-inch definition) now in No. 3 yellow corn would represent approximately 1 cent per bushel if it were a weight deductible. A change to zero deductible foreign material could easily eliminate the need for breakage susceptibility as a grading factor because the incentive to control breakage would be incorporated into the FM discount.

The market value of less-than-whole kernels (in any grain) has not been fully explored. If we assume that more cleaning will be needed for competitive reasons, then effort must be placed on locating optimal uses for cleanings. This is a researchable question best assigned to research agencies in the areas where cleanings would be generated. Several land-grant universities already have established programs that could effectively utilize additional support. Hurburgh (1988) discusses this issue more fully.

The development of a new inspection machine for particle-size analysis is an industry function that most assuredly will be fulfilled if the incentives for clean grain develop. Part of the discounts to be avoided will be invested in such machines. Assuming the unit would cost about $1,000, equipping the roughly 10,000 U.S. elevators, terminals, and other inspection points would cost $10 million.

3.3. Density Measurements

Test weight is a measure of bulk density. Bulk density means the density of a material at rest in some container. This contrasts with material (kernel) density, which is the density (or specific gravity) of the solid material. Bulk density is affected by packing as well as kernel density.

3.3.1. Current practice

Test weight has been a grade-determining factor since the standards were established. It is Officially determined by dropping grain into a 1-qt dry measure from a cone hopper 2.0 inches above the quart kettle (see Figure 3-4). The kettle is "struck-off," and the contents are weighed. The units of measure are pounds per bushel (1 bu = 1.245 ft^3).

Test-weight determination is influenced by moisture content; test weight increases as moisture decreases. Hall and Hill (1973) quantified the relationship for corn as approximately 0.25 lb/bu increase per percentage point decrease in moisture. Test weight increased less if the corn was more physically damaged (Figure 3-5). The Hall and Hill data was supported by Hurburgh et al., (1983) and Hurburgh and Moechnig (1984). High-temperature drying inhibits the test-weight increase relative to low-temperature or natural air drying. Some elevators still discount wet corn for low test weight despite the increase after drying.

There are several estimation methods available for test-weight determination in field situations. They also utilize a filled volume that is weighed, but the filling conditions are much less uniform than for a kettle apparatus in a laboratory. In addition,

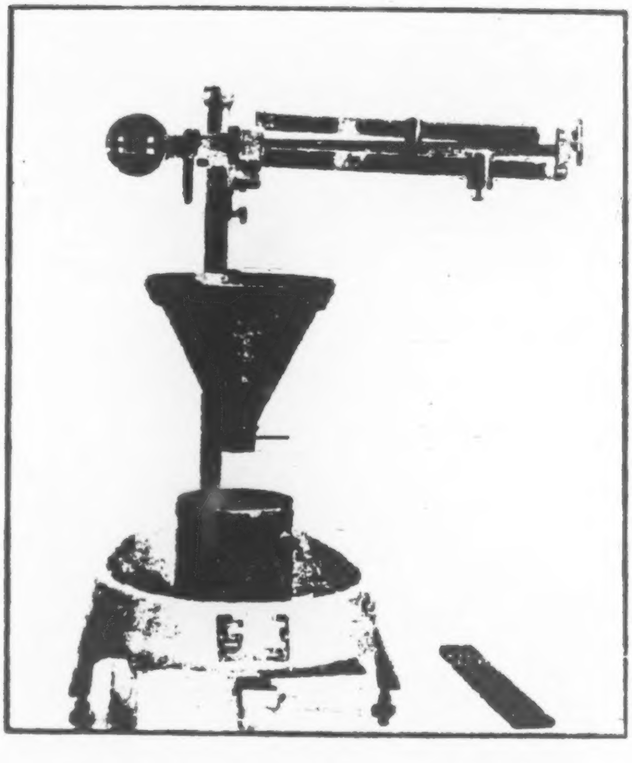


Figure 3-4. Test-weight apparatus.

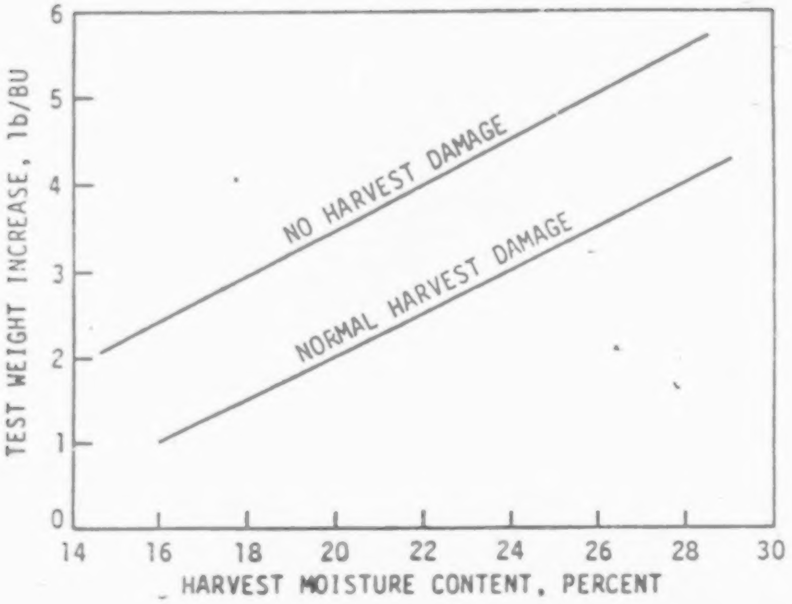


Figure 3-5. Test-weight increase from drying corn. After Hall and Hill (1973).

one moisture meter, Dickey-john GACII, has internal weighing of its sample cup. Test weight is computed and printed out as "approx." weight per bushel. The quart kettle contains 800-1000 g of grain; the GACII test cell, 200-250 g. Some country elevators do trade on the GACII computed test weight, however.

Because most grain from farms meets or exceeds test-weight standards, country elevators often do not measure it. It is rarely grade-determining in corn, soybeans, or wheat according to FGIS data summaries. U.S. exports nearly always exceed contracted limits for test weight (USDA, 1987a,b,).

The air-comparison pycnometer determines kernel density by measuring the amount of air displaced by a 2 to 3-g sample. In this way, kernel stickiness and geometry are eliminated. A pycnometer test requires about 10 minutes. Sampling is a particular concern because only 8-10 kernels are used. Hall and Hill (1973) reported a good correlation of kernel density to test weight at corn moistures below 18%.

Floaters and thousand-kernel weight have been used in many studies to measure density. Floaters are kernels that float in a solution of known specific gravity. The thousand-kernel (seed) weight is a measure of size as well as density because seed volume will affect its value. Seed weights must be corrected for moisture content. The seed-weight test uses a slotted board to trap a set number of seeds for weighing.

3.3.2. Accuracy and standardization.

Test-weight apparatuses for Official inspections are checktested against a master apparatus in Washington, D.C. The acceptable tolerance between master and field apparatus is 0.3 lbs per bushel.

When sampling error is included, the SEP of an Official test weight determination is about 0.3 lbs per bu. for corn and soybeans; 0.2 lbs per bu., for wheat. This agrees well with laboratory data on corn showing a standard deviation among test weight replicates of about 0.3 lbs per bu. (Hurburgh, 1981). Interestingly, test weight is the only Official factor that has a rounding increment (0.5 lb per bu) equal to or larger than the expected uncertainty of the test.

There is no certification program for test-weight apparatuses in house-grade inspections. States that inspect moisture meters may also verify the accuracy of scales that are used to weigh the moisture-test samples. The same scales are used to weigh test-weight grain.

3.3.3. Problems with density measurements

The correlation with moisture remains a corn marketing issue despite strong validation of the effect. Other grains are usually marketed dry. The Hall-Hill adjustment formula could be applied easily to wet-corn data.

Some handlers report that oil application (for dust suppression) lowers test weight 0.7-1.0 lb/bu in corn. The Grain Quality Workshop report called for FGIS to investigate test-weight measurement methods and resolve the oil issue (NAEGA, 1986).

The value of test-weight information remains at issue. The other OTA papers have presented the conflicting data on usefulness of test weight to users. Wheat millers make more importance of test weight in marketing than do buyers of corn and soybeans.

Density is a key parameter in capacitance-cell moisture measurement. Therefore, as long as capacitance moisture meters are used in trade, some method of density measurement will be needed.

3.3.4. New technologies

Test-weight measurements can be automated by use of load cells and microprocessors. However, there has been no recent advance in the overall concept of grain-density measurement. Optical methods for characterizing grain components could reduce the need for density data in preference to endosperm composition and hardness. Test weight is a rapid screening evaluation that will alert buyers to the possibility (although not the certainty) of substandard quality conditions. There would seem little need to expend resources on density measurement technology.

3.3.5. Assessment of needs

Density measurement research is not a high priority relative to other grain quality problems. Dissemination and use of moisture-adjustment scales for corn is a market-information issue, best left for those closest to it. The oil-additive, test-weight question is important but will not require extensive resources to document.

The market has long discounted for low test weight but has not rewarded high test weight. If certain end users (e.g., dry millers) are obtaining extra value from high-test-weight grain, then sellers should collect these facts and apply appropriate pressure to change the situation.

3.4. Subjective Factors

The principal subjective factors are the two categories of damage (total damage and heat damage) and class (as applicable). However, odor (COFO), sour, heating, and distinctly low quality (DLQ) are also at the judgment of the inspector. The latter four are Sample Grade factors with no quantification needed. A discussion of the significance of damage factors is contained in the storage article commissioned for this study.

3.4.1. Current practice

Damaged kernels are hand-sorted from a small subsample. In Official inspections of corn and soybeans, 250 g of cleaned grain are picked. In wheat inspections, 50 g of dockage-free grain are picked for heat damage, 15 g for total damage. The key element in Official procedures is the use of interpretive line slides (ILS) as standards. The inspector compares individual kernels with the coloration of backlighted slides. The ILS are established as the definitions of various types of damage. Kernels that are discolored as much as or more than those shown in the slides are counted as damaged. Each grain has several types of discolorations that contribute to total damage. Heat-damaged kernels are charred completely black.

Procedures for house-grade damage inspections vary widely. A small survey of Iowa elevator operations found many procedures and sample sizes in use (Iowa State University, 1983. Unpublished data.). Local elevators tended to use small (60-120 g) samples and viewed kernels only from one side. None used ILS. Some did not use sample dividers to subdivide analysis portions. A Boerner sample divider will always be used in Official inspections. Of even more significance is the lesser frequency of damage analysis by local elevators.

Damage levels of inbound grain to local elevators are usually below limits for the commonly traded grades. In a 1983-84 study, soybeans from farms averaged 0.2% damage as opposed to the 1.0% allowed in U.S. No. 1 (Hurburgh et al., 1988). So it is not surprising that most elevator operators do not even test grain for damage unless there is an obvious reason to do so. Traders prefer to blend problems off rather than risk alienating a customer. This is somewhat shortsighted for two reasons -- 1) the farmer receives no incentive to be concerned with damage and 2) the elevator should care about small differences in inbound quality because its blending ability is affected. However, as long as the normal amount of damage in the marketing chain is less than the maximum allowed, which by FGIS data it is (USDA, 1987a,b), there will be no incentive to abandon the "station average" pricing system. Damage percentages have been rising slowly over the last three years, probably because of longer storage times.

Warehousing and government program practices interact with damage measurement in that specific factor measurements are not required by USDA or by warehousemen. Rather, the factor limits for the warehouse-certified grade can be used as the statement of quality. This reduces the need for detailed inspections at interior locations. The Grain Quality Improvement Act of 1986 contained a requirement that USDA study offering premiums for above-grade grain forfeited under the loan program. Such premiums would sharply increase the need for skill and objective technology at the country elevator.

The sample grade factors are determined by examination before any other tests are made. The sniff test to measure odor has received considerable attention both for lack of consistency and hazard to inspectors. Recent problems with sorghum odor detection point out that odor can easily be interpreted differently among inspectors. There is no retainable standard for odor that an inspector can refer to in questionable cases.

Class refers to different types within the same grain. Class can be distinguished by color (yellow corn, white corn) or morphological characteristics (the wheat classes). Class will be added to the Official Grade designation as, for example, U.S. No. 2 Yellow Corn. If class is determined by distinct coloration, problems are few. However, the morphological differences among wheat classes have been growing less and less distinguishable because classes have been genetically intermixed to improve yields. Under current procedures, both the physical appearance and the presumed origin of wheat are used to establish class. Each class has allowable limits of other classes. "Mixed" is used to designate class mixtures in excess of Standards limits. For example, yellow corn containing over 5% white kernels would be mixed corn. Wheat classes are much more likely to be mixed than are classes of any other grain. The classing system is maintained because grain classes have different end use properties.

The United States Wheat Standards provide for seven classes: Hard Red Winter Wheat (HRW), Hard Red Spring Wheat (HRS), Soft Red Winter Wheat (SRW), Durum Wheat (DU), White Wheat (WW), Unclassed Wheat, and Mixed Wheat (MW). Three classes, HRS, DU, and WW, are further divided into subclasses based on the percentage of vitreous kernels present. Vitreous kernels are kernels that do not contain yellow or mottled spots and are considered hard textured. This class structure over the years has permitted segregation and marketing of wheats according to their use in the products they are best suited. Each class is based on visual morphological traits typically associated with that class. As new varieties are introduced, they are classed on the basis of their morphological traits when compared with the traditional traits associated with each class.

Nine morphological traits can be used to class wheat. During visual classification, however, only five are predominantly recognized: (1) kernel size and shape (length, width, and back); (2) kernel color and texture; (3) size and angle of the germ; (4) crease and checks; and (5) brush. Table 3-1 provides examples of classical traits associated with HRS and SRW. Wheat is classed by sorting individual kernels in the sample being examined according to the five morphological traits associated with each class. When any sample contains more than 10% of other classes, the sample is considered Mixed Wheat.

HRS

Length:	Short
Width:	Broad
Back:	Generally slopes down from germ to brush
Germ:	Medium with medium angle
Texture:	Rough
Cheeks:	Sharp
Crease:	"V" shape
Brush:	Medium

SRW

Length:	Medium
Width:	Broad
Back:	Slopes down from germ to brush
Germ:	Large with low angle
Texture:	Rough, corrugated, or wrinkled
Cheeks:	Rounded
Crease:	Open
Brush:	Heavy

Table 3-1. Comparative morphological traits of HRS and SRW wheat.

Source: Federal Grain Inspection Service, Board of Appeals and Review.

The visual classification system has come under fire recently because of the difficulty in accurately distinguishing between some varieties of HRS and HRW and between the hard wheats (HRW and HRS) and SRW. This system, however, has been subjected to scrutiny as soon as one variety did not fit the visual system. Dr. Virgil Smail reported recently that, in 1922, approximately 10% of the varieties varied on one or more of the five traits. According to Dr. Smail, today approximately 45% of the varieties seem to have morphological traits different from the typical traits associated with a particular class (Smail, 1987). There are many reasons beyond the scope of this discussion as to why the traditional morphological traits associated with a particular class are no longer applicable. The market, however, places sizable economic value, up to 50 cents per bushel, on class. Mixed Wheat is also discounted relative to any pure class.

In June 1986 the Federal Grain Inspection Service (FGIS) appointed a group composed of grain industry representatives to address the classification problem and provide recommendations for a long-term solution. This resulted from the increasing release of varieties that do not exhibit traditional traits peculiar to their class. During many meetings, this group explored establishing new classes that would include the varieties that do not exhibit traditional traits. Finally, the group focused its efforts on developing objective testing technologies. Their effort can be broken down into two research areas: hard versus soft classification and HRS versus HRW classification.

The hard versus soft classification research is focused on technology that will measure kernel hardness. Currently, two technologies are being examined: single-seed analysis and near-infrared reflectance (NIR). Hardness is also being examined as part of the HRS/HRW classification scheme, but the two technologies previously mentioned have not yet provided a clear-cut distinction between HRS and HRW. Thus, the group is examining other factors that could be used to distinguish between HRS and HRW.

In an effort to gather information, the group, with the assistance of FGIS, has initiated a National Wheat Hardness study. This study is designed to collect samples of HRS, HRW, and SRW and evaluate several experimental single-seed analyzing machines along with the NIR for hardness scores. Additional data will be collected for other factors that could possibly be used to distinguish HRW from HRS.

3.4.2. Accuracy and standardization

By inference from the breakpoints in the cu-sum inspection plan (see 3.8), the SEP of a single Official damage analysis is about 0.9 percentage points, 0.6 points, and 0.6 points for corn, soybeans and wheat respectively. Because damage is a subjective factor, there is no formal reference standard about which to base an SEP. ILS do provide an indirect reference. Therefore standard deviations are expressed among inspectors (Woodall, 1986). The interpretation of the Board of Appeals and Review is the de facto reference standard for all subjective measures, including class.

In a recent test, a farm magazine reporter documented a 7-percentage-point spread among local elevators in grading the same samples. Federal inspectors averaged 7-10 points greater damage than local elevators. Obviously standardization is not good outside the Official system. The same arguments can be made for classing and the sample grade factors.

3.4.3. Problems associated with subjective factor inspections

1. No objective standard.
2. People may interpret ILS differently.
3. ILS not used outside Official system.
4. "Station-average" pricing.
5. Odor detection by sniffing is variable and potentially hazardous.
6. Samples often are not stable over time.
7. Internal insect infestation easy to overlook.
8. Adhered dust and dirt can be confused for damage.
9. Unclear class distinctions in wheat.

3.4.4. New technologies

Gunasakeran et al. (1986) reported that computer vision can distinguish colorations among seeds. Image analysis still presumes that subjective decisions are made to calibrate the analyzer. Some sort of expert-system logic will be required to interpret images. These devices will need extensive computational capabilities.

Production of organic compounds has been related to mold degradation. For example, measurable ergosterol production occurs with nearly all fungal invasion. Thus, the detection of by-products seems to be a valid technology for measuring total or species specific fungal invasion. Site-specific antibodies, used now for toxin detection, could potentially quantify concentrations of indicator compounds.

FGIS' contract research on automated odor detection has produced rapid chromatographic methods for detecting volatiles. However, the specific volatiles associated with deteriorating grain are not well enough known to enable grading of samples.

Single-seed analyzers developed by Kansas State University, the Grain Marketing Research Laboratory at Manhattan, and the ARS-Beltsville are being evaluated in the National Wheat hardness study. In addition to being evaluated for accuracy, these machines are being reviewed for speed. The speed at which an analysis can be performed is critical for implementation in the field. Speed has been the limiting factor in the initial evaluations of single-seed analysis and NIR. Single-seed analysis provides more information on which to base classing decisions than the NIR because the NIR provides an average hardness score. However, the NIR is much faster. A preliminary speed of 400 kernels/5 minutes for single-seed analysis has been established as the speed required for field implementation.

The machine developed at Kansas State University works by measuring the pressure on a horizontal circular cutting blade as it cuts the kernel. The cutting pressure seems to accurately differentiate between hard and soft samples. This machine, because of its system of cutting and rapid cleanout, has the potential of meeting the 400 kernel/5 minute speed requirement.

The machine developed at the U.S. Grain Marketing Research Laboratory in Manhattan measures hardness as based upon the pressure required to crush a kernel as it passes between a concave plate and a mill roll. The plate is hinged to allow the pressure at the time of crushing to be recorded. This machine also is capable of determining moisture content. Moisture content, as well as hardness scores, will be collected because of its possible relationship to hardness. Unless a rapid-feeding device is developed, the fastest this machine can operate is 200 kernels/5 minutes.

The most advanced machine in terms of being ready for implementation is the Norris Hardness Tester. This machine measures hardness by using digitized time to grind measurements. It has the most reliable feeder; however, it is the slowest of the three. The speed of this machine may never exceed 200 kernels/5 minutes.

Calibration equations for hardness have been developed for use in the NIR and are already being used to some degree in the commercial market. NIR readings provide an average hardness score for the sample being analyzed. NIR measures hardness through the particle-size differences in ground wheats of different hardness. Further refinement of NIR hardness calibrations are needed. Data collected from the study will be used in this manner. It is hoped that NIR can be used to provide quick analysis for commercial users. However, the wheat classification task force believes that NIR hardness scores cannot be used as the basis for classing and that single-seed analysis should provide the basis for classing as defined by FGIS. If this approach is finally adopted, correlations between NIR and single-seed analysis will be developed.

To obtain information regarding other factors that may distinguish between HRS and HRW, the samples will be run through a scanning NIR. The information collected from scanning each sample at various wavelengths will be evaluated to determine if factors other than hardness can be used to distinguish between HRS and HRW.

In addition, a portion of the samples will undergo milling and baking tests.

This study is just under way. Information collected so far indicates that hardness can be used to distinguish between hard and soft wheat. No decisions will be made regarding the hardness score that will ultimately be used to distinguish between hard and soft wheats until the study is completed. Information from the scanning NIR will be evaluated to determine if other factors can be used to distinguish between HRS and HRW.

3.4.5. Assessment of needs

Subjective tests are by nature nearly unstandardizable. FGIS' efforts with the ILS and odor detection are creditable, but will not eliminate human variability in damage measurements. Furthermore, standardization outside the Official system is impossible. Therefore, immediate priority should be placed on obtaining the basic biological data necessary for design of objective electronic systems. Public research agencies need to generate feasible concepts upon which industry can build. A central lab such as one of the USDA-ARS facilities would have better access to basic research equipment than would individual university programs. This work will be costly and tedious. Five years of odor research by USDA has established methodology for detecting odor but has not revealed the specific compounds associated with grain odors. The research should include the entire gamet of subjective factors.

More sophisticated analysis probably will enable more than two gradations of damage. Market values need to be assigned to gradations, properties determined, and reasonable tolerances set. These questions seem suited to localized research.

Damage is on the increase because of U.S. storage policies. Damage will be the quality issue of the next five years. Examination of standards in advance of the impending problem would be time well spent.

The wheat classification-hardness work is a classic example of technology applied to remove human error. If successful, a subjective factor will be eliminated in favor of an objective, reproducible one. The consortium of persons and agencies involved in the work demonstrates the power of the market to muster resources when economic pressures are felt. Misclassing affects buyers, handlers, and sellers. Mixed wheat is inferior wheat to nearly any miller. Additional outside resources do not seem necessary to maintain interest in solving this problem. Those concerned with changing standards and applying new technologies would be well advised to study the market dynamics of the wheat classing issue.

3.5. Compositional Measures

Measures of grain composition (protein, oil, starch, fiber) are emerging as an important new classification of factors. They were identified by both the Grain Quality Improvement Act and the Grain Quality Workshops (NAEGA, 1986) as critical to the concept of end-use value. Compositional factors relate to every major end use of corn, soybeans, and wheat.

3.5.1. Current practice

Wheat protein is the only compositional factor measured in the Official system. Other factors of emerging interest are soybean protein, oil, and fiber; corn protein, oil, starch, and fiber. All compositional factors have wet-chemical reference methods.

Rapid testing is done with a near-infrared reflectance analyzer by utilizing the selective reflectivity of organic chemical structures to light in the 900 to 2500-nm range. NIR is a comparatively recent technology first explored by Massie and Norris (1965) and commercialized in the early 1970's (Butler, 1983). Protein in wheat is a critical factor in breadmaking; therefore, NIR technology has been extensively reported by American Association of Cereal Chemists. Refer to Williams and Norris (1987) for a comprehensive description of NIR principles and applications.

NIR results are obtained from reflectance measurements (typically in log (1/R) units) at various wavelengths. Spectral patterns are demonstrated in Figure 3-6 by using moisture as an example. The composite spectrum of a sample is the sum of the spectra for reflective constituents. Thus, calibration of NIR is a statistical matching of spectral response in selected wavelengths with wet-chemistry values. There are many mathematical procedures for this matching, depending on the type of instrument used. Although a detailed presentation of NIR mathematics is beyond the scope of this paper, there are two general types of instruments.

1. Scanning monochromator units collect data every 1-4 nm across the spectrum. Thus, they can sense rates of change of reflectance. Monochromators can be calibrated to select exact peaks and valleys for constituents. Monochromators require extensive computation capabilities and cost from $25,000 to $75,000 per unit.
2. Fixed filter units collect data at preset wavelengths. Their calibration is statistical because the wavelength choices are fixed. However, they are less sensitive to sample preparation and procedural variations. Fixed filter units typically cost $8,000-$15,000 per unit.

FGIS uses fixed-filter NIR units to measure wheat protein in Official inspections. Procedures are described in a handbook (USDA, 1987c).

Many studies have demonstrated that sample consistency (grinding) and sample set diversity are the key parameters determining NIR performance. Particle-size changes shift the spectrum up or down, although not necessarily equally at all wavelengths, as shown in Figure 3-7. Diversity means including all the possible relative constituent combinations and reflectance-constituent relationships in the calibration set.

Besides wheat, NIR has been successfully applied to corn (Hymowitz et al., 1974; Lai et al., 1984) soybeans (Hurburgh et al., 1988; Rinne et. al, 1975) and other materials. In all instances, the NIR principle was able to determine compositional factors with an R^2 value greater than 0.80.

3.5.2. Accuracy and standardization:

There have been many studies of NIR performance relative to wet chemistry. Table 3-2. is a summary of findings. Reports were remarkably consistent. However, most SEP data were collected in the same laboratory with the same procedure and equipment used for calibration. This will underestimate SEP's of field units with different grinders and operators.

For any of the analyses, NIR is usually precise (repeatable) to within ±0.2% on the same ground sample. Regional and repack errors will increase within-sample variability.

FGIS standardizes NIR units by daily testing of known-composition wheat samples. NIR units are biased up or down on the basis of average errors. This process can lead to overcorrection of the

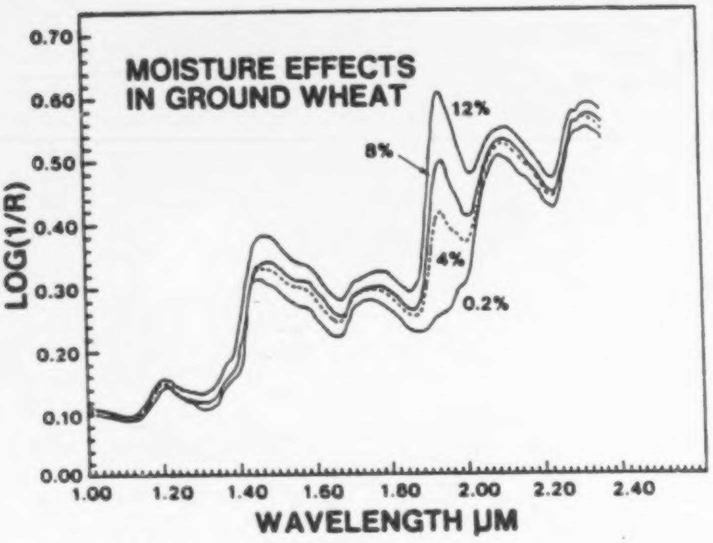


Figure 3-6. Spectral response of ground wheat to moisture content (Dickey-john, Inc. 1984).

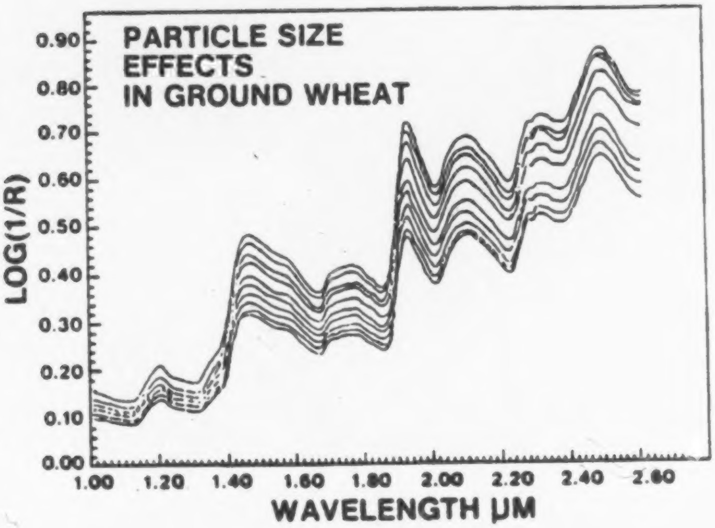


Figure 3-7. Spectral shifts from changes in particle size. (Dickey-john, Inc., 1984)

Grain	Constituent	Approximate SEP, percentage points	Typical range of constituent percentages
Wheat	moisture	0.2	8-15%
	protein	0.4	8-17%
Corn	moisture	0.2-0.3	8-35%
	protein	0.3-0.5	6-10%
	oil	0.3-0.4	2-5%
	starch	0.8-1.2	57-65%
Soybeans	moisture	0.2-0.4	6-20%
	protein	0.4-0.6	30-42%
	oil	0.4-0.6	15-23%

Table 3-2. Approximate standard errors of prediction (SEP) for near-infrared reflectance.

units based on sampling and other variations rather than true instrument error. NIR units are remarkably stable. In 1986, a two-year-old soybean calibration gave average errors of 0.07, 0.01, and 0.14 percentage points for soybean moisture, protein, and oil, respectively (Hurburgh, C. R., Jr., Iowa State University, unpublished data, 1987).

A troubling issue to NIR calibration is lack of consistency in the reference standards. Iowa State data showed 2-3 percentage points variation among laboratories in soybean wet chemical methods (Hurburgh, C. R., Jr., Iowa State University, unpublished data, 1984). NIR studies report the correlation with one wet lab, but in commerce, many wet labs will be used to monitor accuracy. Inconsistent standards will lead to confusion and eventually to the collapse of any expanded compositional testing program. A collaborative study organized by USDA and Iowa State University is investigating this problem (Hurburgh, 1987b).

NIR units of the same brand are not identical which means that the same calibration constants cannot be universally used. Calibration transfer involves either a slope and bias adjustment to calculated percentages (USDA, 1987c; Butler, 1983) or spectral adjustment equations by wavelength (Schenk et al., 1985). The spectral adjustment is more accurate, and less sample-set dependent but requires the same prepared cups be presented to all instruments being matched. The spectral adjustment method is being evaluated by the collaborative study.

NIR calibrations require continuous monitoring for accuracy. Lack of monitoring led to the recent controversies over the accuracy of FGIS wheat protein certifications. The calibration must always contain the full range of spectral properties and grinder-procedural variations that will be encountered in practice. Otherwise the NIR will be overly sensitive to inevitable variations. Selecting the calibration sample set to provide maximum R^2 and/or minimum standard deviation of calibration will not assure maximum accuracy on unknown samples having no connection with the calibration set. Acceptance of these principles will be key to the use of NIR in country elevators for routine prediction, especially in coarse-seeded grains that do not grind easily.

3.5.3 Problems with NIR

1. Calibrations must be updated continuously.
2. Calibration transfer will be needed for every instrument.
3. NIR units are costly. About $25-$50 million would be needed to equip local buying stations with NIR. Most FGIS offices, delegated states, and designated agencies have them.
4. The standard reference methods are not consistent across labs.

5. Some inexpensive periodic check-test method will be needed.
6. Grinding requires operator skill and knowledge.
7. The market tends to trade factors more precisely than the unit can measure them.

3.5.4. New or alternative technologies

Whole-grain transmittance of near-infrared light can be used to measure the same constituents as NIR. Whole-grain NIT is inherently simpler than ground-grain NIR but is influenced by irregularities in the grain, especially in coarse-seeded grains. There have not been extensive published reports on NIT; our experience suggests that NIT could have an SEP 1.2-1.5 times greater than that of NIR with current technology. NIT eliminates grinding errors but introduces sample packing and temperature considerations. Further advancement of whole-grain testing will be important to general market acceptance of compositional testing.

There are other wet-chemical methods, but these are, in general, impractical for the one-per-minute requirements of a grain elevator. The rapid digestion-colorimetric protein method (Hach et al., 1985) and the tetrachloroethylene oil extraction method may offer promise as secondary standards for checking NIR.

3.5.5. Assessment of needs

Technological needs center on the refinement of calibration/transfer procedures and on the development of automated NIR or NIT systems. Public funding should focus on application rather than instrument development. FGIS undoubtedly will be the focal point for spreading compositional testing. The Official methods for calibration development and transfer will be the basis for the rest of the trade. Therefore, it is vital that FGIS research efforts be well coordinated with other public and private work.

Basic reference methodology must also be standardized. Several professional societies are attempting to resolve this problem, but the voluntary nature of such efforts will limit progress. Inconsistencies among reference methods are a problem only if these measures are used in trade. Therefore, public funds will be needed to support these private scientific efforts.

Spectral properties will continue to be the basis for rapid compositional measurements. This technology is comparatively young. Thus far, the efforts have centered on application rather than fundamental relationships. There is great need for basic spectral research at the molecular bonding level to better clarify what is and is not being measured by reflectance and transmittance instruments. There is also need for materials research to find inert reflector materials that could be used as check-test standards. Powdered sulfur has been proposed as one such material.

The public research topics just mentioned will require about \$2-\$4 million annually for 5-10 years. A key component to success will be coordination of efforts among researchers in the area. The duplication of effort, as reported in various scientific journals, was most striking. There is a scientific user-network in forages; the USDA-ISU collaborative study seems to be the beginning of a similar effort for soybeans. However, each commodity should not need its own group; there must be some mechanism for overall information sharing and problem discussion. Compositional analysis is unique in grain-quality testing because very sophisticated technology must be placed in field situations. With this concept of coordination comes a requirement that the standardizing agency, FGIS, must be part of the overall scientific effort and must not attempt to establish its own procedures.

3.6. Hardness and Breakage Susceptibility

Hardness measures the intrinsic shear resistance of grain kernels. Breakage susceptibility measures ability to resist breakage after impact.

In corn, the distinction is fuzzy because corn is inherently more breakage prone than small grains and because corn kernel strength properties change dramatically with drying methods, combine settings, and handling. Any tester that measures hardness will be influenced by the stress cracking that leads to breakage susceptibility. Corn hardness particularly relates to yields of large grits in dry milling. If measured on gently shelled, air-dried corn, hardness is essentially the ratio of hard yellow to soft white starch.

Wheat kernel properties remain much more constant; kernel breakage is not a major problem. Thus, wheat hardness, a genetically determined property, is essentially unchanged after harvest. Wheat hardness is correlated with protein content and affects millability. Wheat hardness measurements are closely related to wheat classing because wheat is divided into four classes according to growing season (spring or winter) and hardness (hard or soft). Wheat classing was discussed in section 3.4.

There has been no indication that hardness or breakage susceptibility is an economically important factor for soybeans.

3.6.1. Current practice.

There is no measurement of hardness or breakage susceptibility in corn or soybean standards. However, there is a variety of "breakage testers" that can be used for corn. The Stein breakage tester was the first such device; it has been modified and correlated with actual handling breakage (Eckhoff et al., 1988). The slowness of the Stein procedure led to the construction of the

Wisconsin Breakage Tester (WBT) (Singh and Finner, 1983). The Stein test requires about 5 minutes; the WBT about 2 minutes. The WBT (Figure 3-8) is a large centrifugal impact device that has been extensively tested by several universities (Watson and Herum, 1986). The WBT does not relate as well to actual breakage as the Stein. It does give more breakage in strong samples, which is better for differentiating samples, but worse for predicting actual handling breakage. There have been other breakage devices developed by individual researchers. All involve some method of impacting kernels against a solid surface. The WBT spins kernels on a rotating disk with centrifugal force accelerating them against the outer ring. All devices require the impacted sample to be screened to obtain the percentage broken kernels.

Paulsen and Hill (1985) related test weight and breakage susceptibility to dry-milling yields. Thus, a combination of density and breakage resistance probably defines hardness. Pomerantz et al. (1986) used the Stenvert mill to measure corn hardness. The Stenvert test involves measuring the volume of flour resulting from the grinding of a known sample weight. Correlation of Stenvert readings with end-use value has not been made.

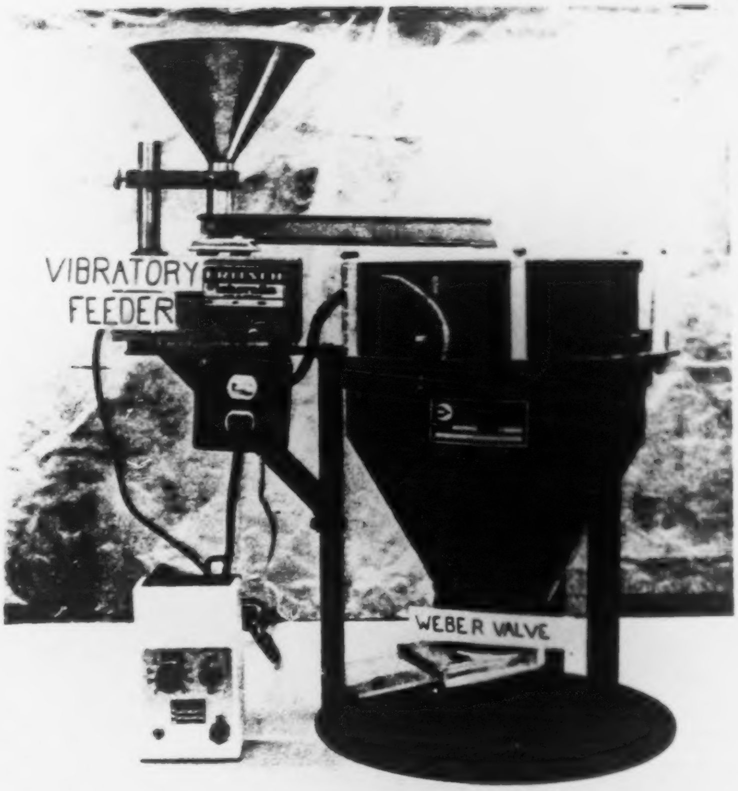

VIBRATORY FEEDER
WEBER VALVE

Figure 3-8. Wisconsin Breakage Tester.

3.6.2. Accuracy and standardization

The coefficient of variation (standard deviation divided by mean value) among breakage testers is 6-12% on a given sample (Watson and Herum, 1986). This is greater than most grain-quality tests. Hurburgh and Moechnig (1984) and Hurburgh (1984) found that sampling was a major source of error in breakage susceptibility testing. With sampling error included, the coefficient of variation of a single breakage susceptibility test is 20-30%, extremely high for market acceptance. There is no fundamental reference test for breakage susceptibility. Undoubtedly, lack of precision has retarded interest in breakage testers as grading devices.

Breakage susceptibility increases as moisture decreases. Dutta (1986) proposed the following correction equation:

(3-1) $B_f = B_o(1.40)^{Mo-Mf}$

where:

B_o, B_f = original, final Wisconsin breakage susceptibility, %

M_o, M_f = original, final moisture, %

Equation (3-1) translates into approximately a doubling of breakage susceptibility for every 2-percentage-point drop in moisture content. Hurburgh et al. (1988) applied the same functional form to soybean breakage susceptibility. For soybeans, the 1.40 constant was replaced by 1.22.

3.6.3. Problems with corn hardness and breakage susceptibility testing

1. Poor precision and large sampling errors.
2. Lack of interpretation of data.
3. Large relatively slow devices.
4. Sensitivity to moisture content.
5. Intercorrelation of density, moisture, hardness, and breakage susceptibility.

3.6.4. New technologies

There is continuing development of corn breakage testers because an acceptable device for trade has not yet been constructed. Breakage testers are and probably will continue to be mechanical devices. The current WBT costs about $2,000.

Computer vision/image analysis has been used to identify both hard and soft starches in corn (Gunasakeran et al., 1986) and tentatively hard-soft varieties in wheat. This has been done via coloration (corn) and kernel shatter patterns (wheat). At the moment, the equipment is costly (over $10,000) and not well suited to elevator environments. Other wheat classing/hardness technology was discussed in section 3.4.

Chowdhury (1978) demonstrated that exposed starch will bind fast green dye. The dye can then be resolubilized in strong NaOH to give a colorimetric reading (at 640 nm) of stress-cracked kernels. This principle is the basis for one grain-damage meter. It is currently being automated to eliminate manual handling of liquids. The dye index is a sensitive measure of grain breakage (not breakage susceptibility) that is insensitive to moisture content. Dye indices should be of use in storage and milling. Hurburgh and Moechnig (1984) reported that the dye method quantified increases in stress cracks from drying. It has also been used to evaluate shelling methods. Instrument cost would likely be in the $2,000-$5,000 range.

3.6.5. Assessment of needs

The development of corn breakage testers has consumed considerable research effort in the last ten years. Breakage testers have not been put into production because the market value of the information has not been established. Public research agencies would do much better to focus on interpretation rather than instrument design. There is great need for engineering data relating the forces exerted on grains during handling to those experienced in a breakage tester. Breakage testers, including the WBT, have been designed to break kernels rather than subject them to precisely controlled and quantifiable forces. This basic data would shed light on the type of machine required.

The economic distinction between stress cracking, breakage susceptibility, and hardness is unclear. If any of the devices to measure these properties is to gain market acceptance, this distinction must be quantified. For example, a soft-endosperm corn that has low breakage susceptibility because it was handled carefully will probably mill differently than a hard-endosperm corn that is low breakage susceptibility despite abusive drying and handling. Efforts to promote "high-quality" export grain shipments will end in frustration if based on incomplete or inappropriate interpretations of data. If a more restrictive corn FM standard will provide incentives to control breakage susceptibility, then the hardness property should be the focus of future research.

As with damage, there is much needed basic data on optical properties, colorimetry, etc. Such data are essential to refinement of optical expert systems for measuring cracked kernels, endosperm composition, or internal stress fractures.

3.7. Wheat Milling Factors

There are many tests relating to the functional properties of wheat and wheat flour. Most are cereal-chemistry oriented and are thus limited to chemical laboratories in flour mills. However, two, falling numbers and alpha amalyse, are gaining acceptance in trading situations.

3.8. Sampling Methods, Sampling Plans, and Loading Plans

No test result can be any better than the sample it was run on. Grain samples are typically 0.0001 or less of the grain mass being represented. Accurate inspection requires this tiny fraction to be representative of the entire lot. No wonder that an entire book of FGIS procedures is devoted to sampling (USDA, 1980d).

Sampling methods, sampling plans, and loading plans are used to control sampling errors. Sampling methods are the actual devices and operating procedures for collecting samples. Sampling plans are established patterns for using sampling methods on grain lots. Loading plans are requirements for uniformity among sublots, components, or other defined segments of a larger lot. In essence, this distinction represents the sources of sampling error -- the individual sample, the composite of samples for analysis of a sublot, and the composite of sublots to represent a lot. The loading plan, combines test results as well as samples; therefore, it reduces analysis variability as well as sampling variability.

Some factors are more sampling oriented than others. Particle-size factors, breakage susceptibility, stress-crack percentage, and sometimes moisture content have 50% or more of their variability contributed by sampling. The data supporting this statement were largely derived from studies of truck lots delivered by growers.

3.8.1. Current practice

There are two general classifications of grain sampling equipment -- in stream and at rest. In-stream sampling obtains samples at intervals from moving grain; at-rest samplers obtain samples from stationary lots.

In-stream sampling

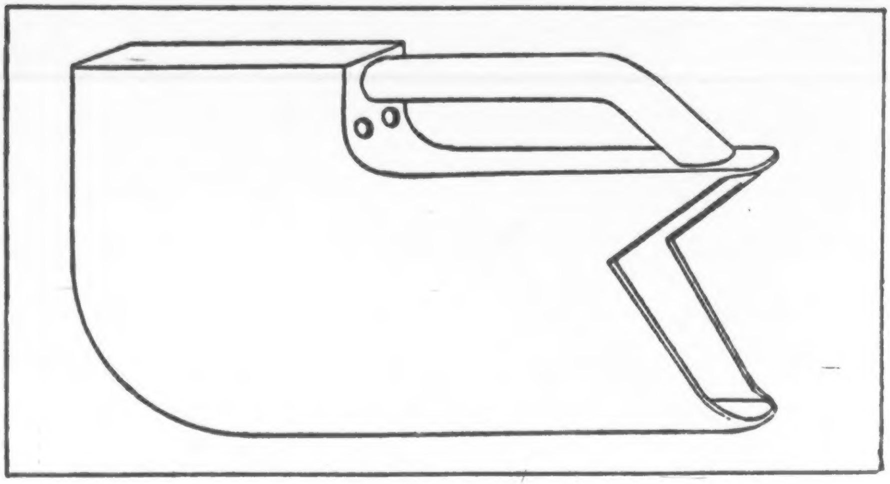
In-stream sampling can be done either manually or mechanically. The Ellis cup and the pelican (Figure 3-9) are used to manually sample moving belts and flowing streams, respectively. Mechanical diverters (DT's) are installed in spouts to sample large streams. The operating principle of a DT sampler is depicted in Figure 3-10. The DT is the most accurate sampling method available (Kramer, 1968a). In-stream sampling in general is more representative because grain is sampled frequently and because flowing grain is more homogeneous than stationary grain.

All export cargos and many interior barge and rail shipments are sampled with DT samples. DT's provide large samples, which must be reduced in a secondary sampler to the size needed for inspection. Inspection samples are further split in a laboratory sample divider to form work and file portions. FGIS procedures are quite detailed about the timing of DT cups, the amount of sample that must be collected, and the handling of samples. However, it is important to recognize that every subsampling operation as well as the initial sample collection, contributes potential error to the final result. A shipper must allow for sampling variations as well as the established error of laboratory testing procedures.

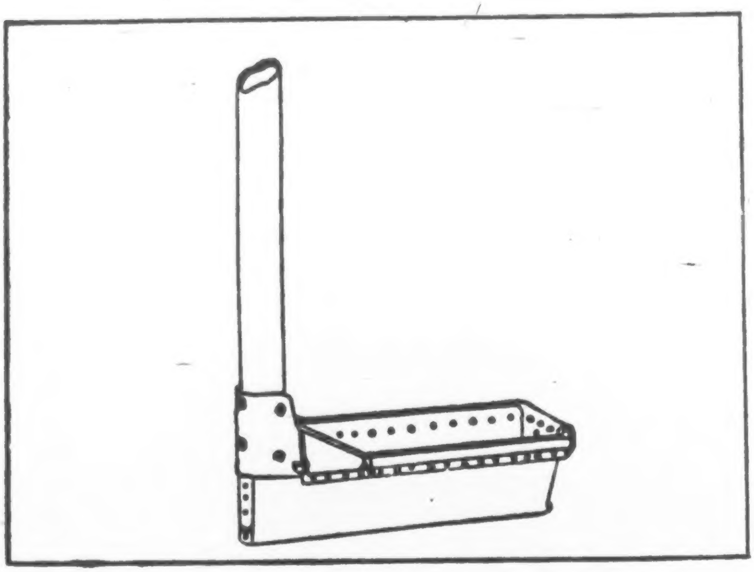
The initial installation of a DT sampler is checked with the pelican. DT systems cannot be checked at full capacity if their flow rates are more than 10,000 bushels per hour because the pelican cup overflows before it gets through the stream. However, DT accuracy is not affected by flow rate (Kramer, 1968b), and the pelican is only slightly more variable than a diverter (Kramer, 1968a).

At-rest sampling

Stationary grain is usually sampled with a probe. Compartmented hand probes (Figure 3-11) can be used for Official inspections of trucks, railcars, and barges. Because a probe samples only one point in the grain mass, multiple sampling



ELLIS CUP



PELICAN

Figure 3-9. Ellis cup and pelican samplers. (USDA, 1980d)

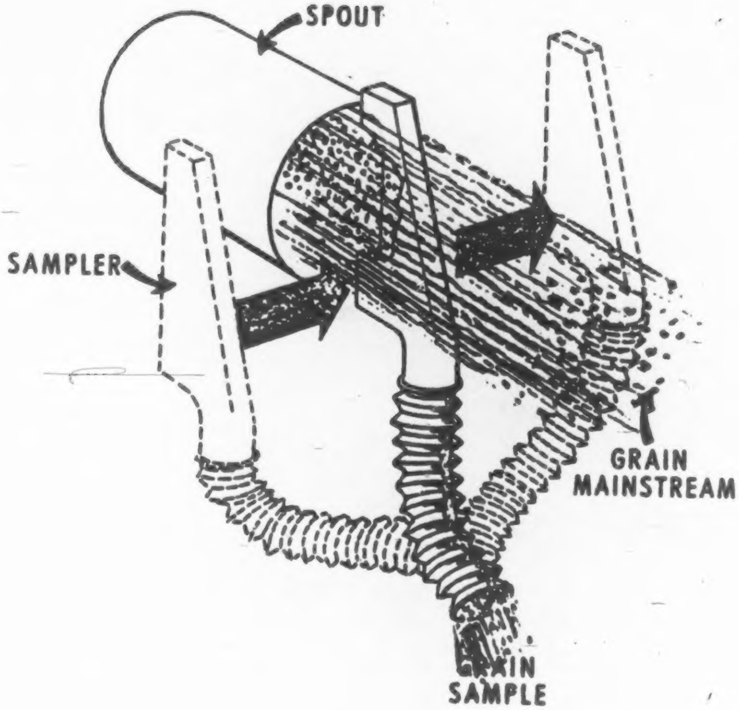

SPOUT
SAMPLER
GRAIN MAINSTREAM
GRAIN SAMPLE

Figure 3-10. Operating principle of a diverter sampler. (Kramer, 1968a)

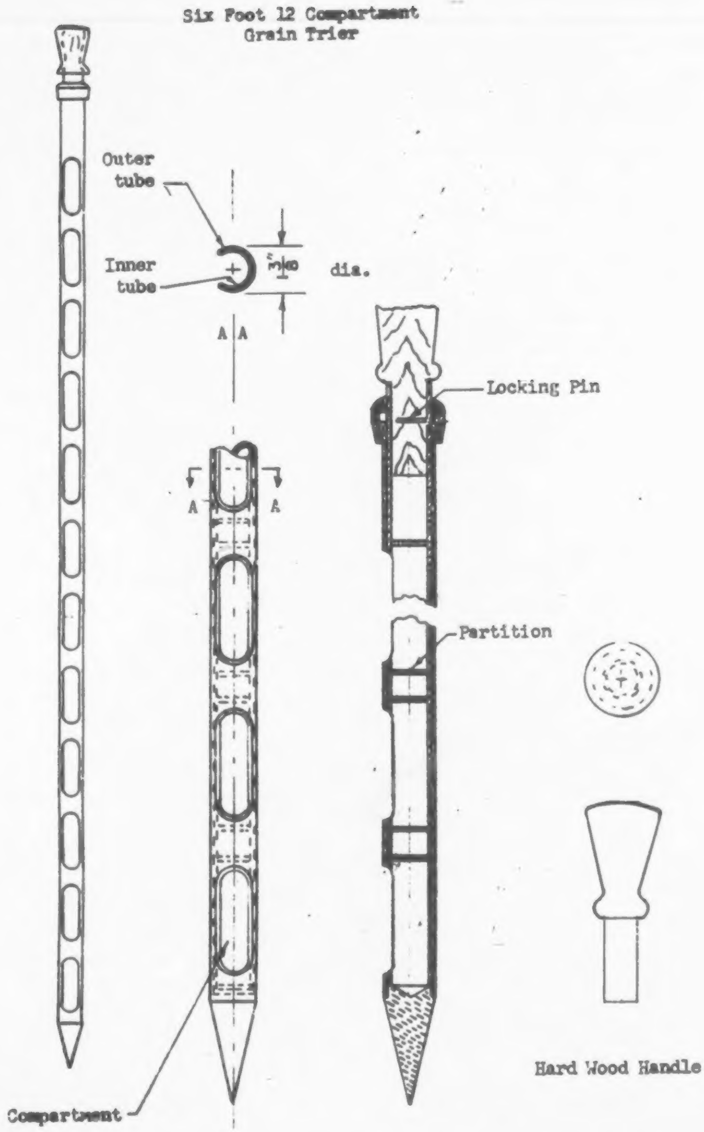

Six Foot 12 Compartment
Grain Trier
Outer tube
Inner tube
3/8"
dia.
A
A
A
A
Locking Pin
Partition
Hard Wood Handle
Compartment

Figure 3-11. Hand probe. (USDA, 1980d)

patterns (plans) are critical. The FGIS sampling plan for probing railcars is shown in Figure 3-12. Probe sampling plans were developed to counteract the inevitable segregation of particle sizes in grain at rest. Hurburgh and Bern (1983) reported that FGIS' truck-probing plan yielded samples equivalent to the pelican. However, probes often cannot reach the bottom of barges or railcars, which has led to a request that probe inspections be reported on a different color of certificate than DT inspections (NAEGA, 1986).

Mechanical probes are common at country elevators. Figure 3-13 shows the general configuration of mechanical probes. Mechanical probes may be used for Official truck inspections, provided that the specific probe installation has been check-tested against the pelican. Mechanical probes are a great benefit to elevators, but there are major differences in accuracy among brands. One of three sample-collection methods is used in a mechanical probe, as shown in Figure 3-14:

1. Vacuum. The sample is pulled into the collection tube by vacuum.
2. Gravity-fill. The sample flows into the collection tube by gravity, as in the hand probe.
3. Core. A round or square core of grain is sliced as the collection tube is inserted.

3-Compartment, Trough or Door Type

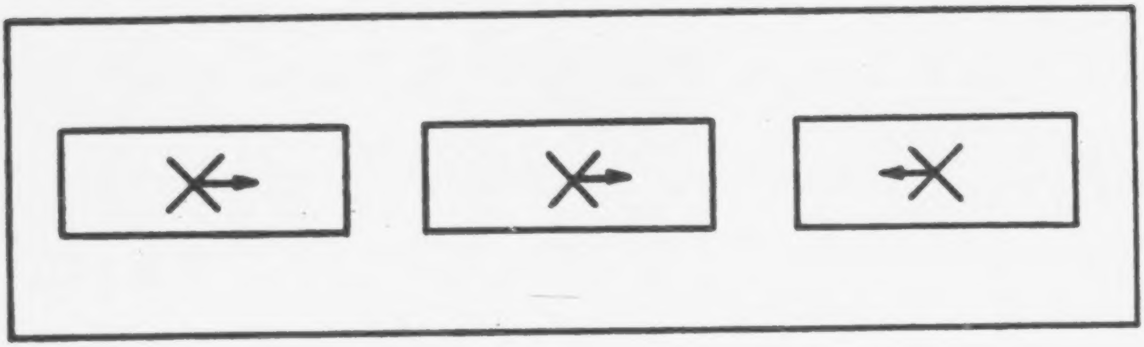


Figure 3-12. Sampling plan for probing railcars. (USDA, 1980d)

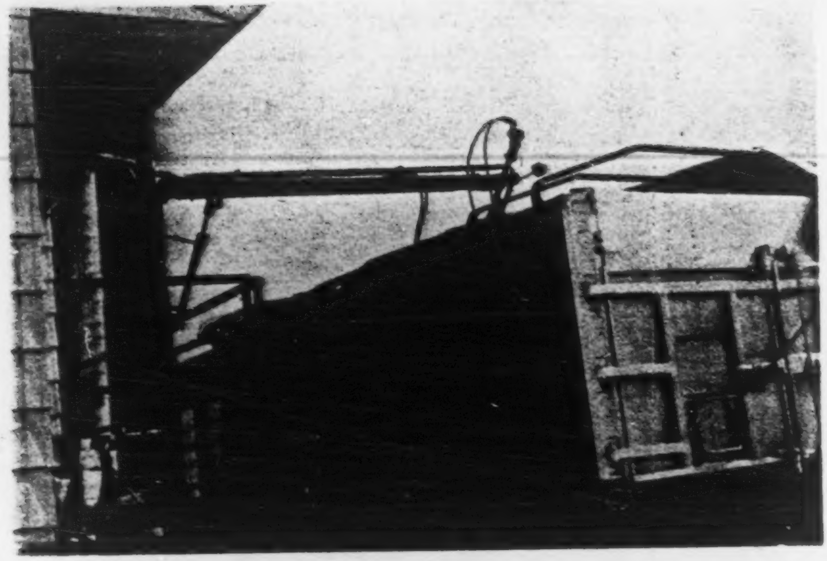


Figure 3-13. Mechanical probe.

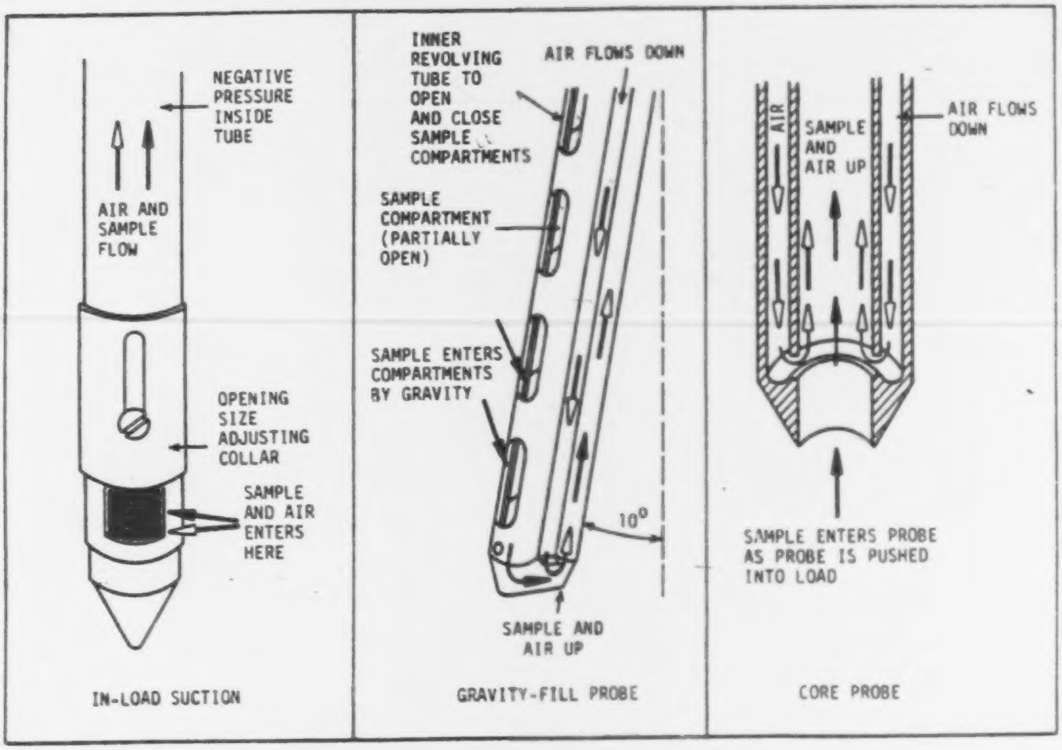

NEGATIVE PRESSURE INSIDE TUBE
AIR AND SAMPLE FLOW
OPENING SIZE ADJUSTING COLLAR
SAMPLE AND AIR ENTERS HERE
IN-LOAD SUCTION
INNER REVOLVING TUBE TO OPEN AND CLOSE SAMPLE COMPARTMENTS
AIR FLOWS DOWN
SAMPLE COMPARTMENT (PARTIALLY OPEN)
SAMPLE ENTERS COMPARTMENTS BY GRAVITY
10°
SAMPLE AND AIR UP
GRAVITY-FILL PROBE
AIR
SAMPLE AND AIR UP
AIR FLOWS DOWN
SAMPLE ENTERS PROBE AS PROBE IS PUSHED INTO LOAD
CORE PROBE

Figure 3-14. Types of mechanical probes.
(Hurburgh and Bern, 1983)

Vacuum probes exaggerate the foreign material content of corn and soybeans by 1-5 percentage points (Hurburgh and Bern, 1983). Vacuum probes are not legal for trade in Iowa, Kansas, or Nebraska. They can be used in other states. However, no manufacturer currently produces a vacuum probe; all are either gravity fill or core.

Although the hand probe is considered the standard for probes, it also overestimates the concentration of small particle sizes. In sampling corn of known BCFM concentration, the hand probe collected significant extra BCFM, as shown in Figure 3-15. Errors increased with the square of BCFM content. Gravity-fill mechanical probes have the same collection principle as the hand probe. As a group, core probes collected the most accurate samples.

Country elevators will make one or two probings per truckload, as contrasted with the 5-9 probings required by FGIS procedures. At a country elevator, there is neither time nor sample handling capacity to composite many individual probings. Limited sampling makes the result vulnerable to nonuniformity within the load. Figure 3-16 shows the typical segregation of small particle sizes in the center of loads. Hurburgh (1987c) proposed two probings taken from the shaded area of Figure 3-17 as a reasonable compromise between accuracy and speed.

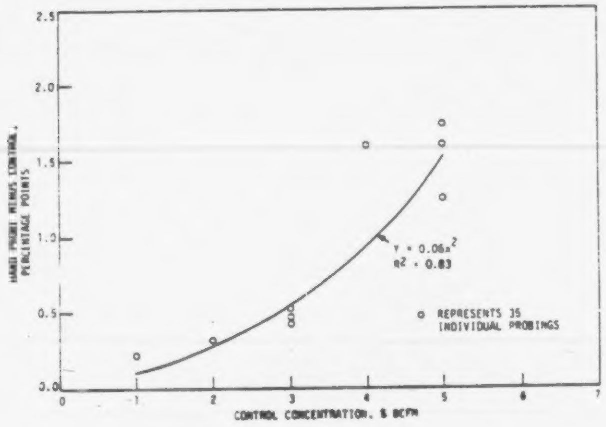
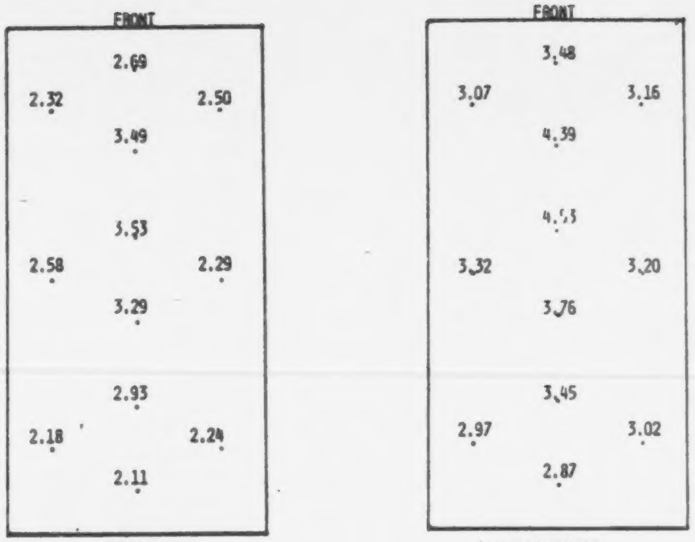


Figure 3-15. Accuracy of the compartmented hand probe. (Hurburgh and Bern, 1983)


FRONT
2.69
2.32
2.50
3.49
3.53
2.58
2.29
3.29
2.93
2.18
2.24
2.11
FRONT
3.48
3.07
3.16
4.39
4.53
3.32
3.20
3.76
3.45
2.97
3.02
2.87

CORN
Percent BCFM

SOYBEANS
Percent FM

Figure 3-16. Distribution of smaller particle sizes in corn and soybeans. (Hurburgh, 1987c)

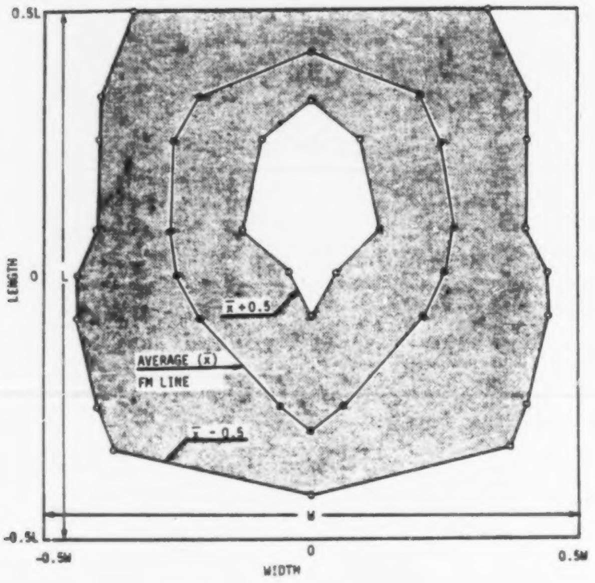


Figure 3-17. Truck sampling locations that contain corn BCFM or soybean FM within 0.5 percentage point of the load average. (Hurburgh, 1987c)

Loading plans

Loading plans are generally used for ocean vessels. Barge-loading elevators sometimes "quarter" barges -- analyze four samples each representing about 25% of the cargo -- but this is only for internal decision making. The Official certificate will be based on a single composite sample for the barge. A loading plan is necessary when the quantity being inspected is larger than can be reliably represented by a single inspection result. Unit grain trains do not require a loading plan because each car (about 3500 bu) can be handled as a separate unit.

The inevitability of random errors can lead to misgrading of grain lots at or near quality limits. Random error is simply an inevitable but inconsistent discrepancy from the "true" value. It arises in sampling, sample handling, and testing. The key point is that random error is not structured and has no preference for either high or low results. Random error has practical consequences in rendering uncertainty to inspection results. The chances for approving or rejecting a grain lot are given by an operating characteristic (OC) curve. FGIS (USDA, 1980e) presents a generic OC curve for online grain inspections (Figure 3-18). The units of an OC curve are percentage chance of acceptance (Y-axis) vs. standard deviations (SEP's) from the acceptance limit. From Figure 3-18, if one wished to have a 95% certainty of acceptance, quality at least

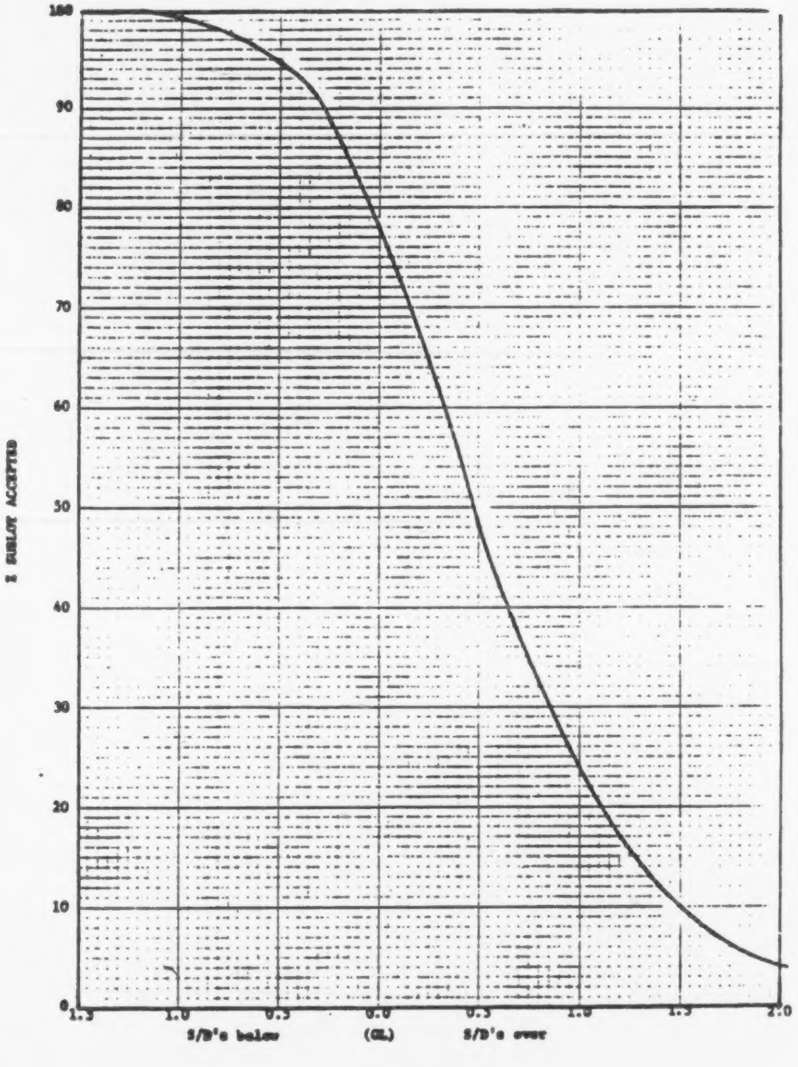


Figure 3-18. Operating characteristic curve for on-line grain inspections (USDA, 1980d)

0.5 standard deviations (with all variance components included) below the limit should be loaded (targeted). A different, flatter OC curve describes single-lot inspections, for which accept or reject is based on one test on one sample. On-line plans are needed when the overall lot size (e.g., vessel) is too large to be represented by a single sample. On-line plans are methods for aggregating a continuum of results into single set of values for the certificate.

The larger the lot size, the greater is the economic effect of targeting below the grade limit. The penalty is the cost of procuring higher quality grain, the cost (risk) of unloading and reloading offgrade lots, or the loss if the offgrade lot must be sold at a discount. Typically, export vessel shipments cannot be sold at a discount while inferior cargos (truck, barges, railcars) can. Typical lot sizes offered for inspection are tractor trailer (800-1,000 bu.), railcar (3,500 bu), barge (50,000 bu) and vessel (500,000-3,000,000 bu). Loading plans, as contrasted with sampling plans, are a method for reducing the effects of random error by current procedures. The cu-sum (cumulative sum) shiploading plan is used to account for variability in inspecting vessel lots. The vessel is divided into sublots of 20,000-60,000 bu, for inspection purposes.

Sublots are graded individually as the vessel is being loaded. If, for any factor, the sum of accumulated deviations (cu-sum) of sublot results from the grade standard exceeds the preset breakpoint, the sublot causing the breakpoint to be exceeded is declared a material portion. It must not be loaded unless an appeal yields a result which will not "break" the cu-sum. If already loaded, it must be removed. The shiplot certificate is calculated from the weighted average of all acceptable sublots.

Cu-sum is a common method for acceptance sampling. But it presumes that one and only one inspection will be done. The breakpoints are calculated as 1.625 times SEP of a single inspection. Multiple inspections (appeals) effectively reduce SEP and thus allow more tolerance for the seller. With reviews, the seller faces a smaller standard deviation than that the OC curve was based on and therefore can target for a quality closer to the grade limit. Woodall (1986) contended that, with the current three reviews and replacement of results, a shipper could target for quality 0.5 standard deviations over the grade limit and still retain a 95% chance of acceptance. In practice, only poor-quality lots are appealed, which means that the odds of obtaining a more favorable result on appeals are good. However, many critics of cu-sum have overlooked the fact that the cu-sum SEP's and breakpoints include only inspection variability and not sampling variability. The data base for establishing breakpoints was drawn from comparative analyses on file and work portions. It did not include sampling errors. This explains why shippers contend that their actual targets are never as close to the grade limit as predicted by FGIS' OC curve studies.

Removal of bias in the cu-sum plan was the purpose for the Woodall study. Proposed revisions (Shipman, 1987) have generated intense debate. These revisions would require averaging of appeal and original inspection results, revise breakpoints to conform with Woodall's estimates of SEP, and define a material portion as all previous sublots over the grade limit rather than just the sublot that potentially would exceed the breakpoint.

In any form, a cu-sum loading plan will always allow passage of some lots that nominally exceed grade limits. Statistically, this is valid because there is uncertainty as to whether the "true" quality of the nominally poor sublots is actually below grade. Perceptually, the United States may never completely convince buyers of its legitimacy. A better plan might be to reduce the standard deviations of sublot inspections as much as possible, then allow no sublots to exceed the grade limits. FGIS is now looking at such actions (Shipman, 1987); this research should be encouraged to whatever extent possible. Currently sublot samples are visually inspected in components, 10,000 to 15,000-bushel increments. If, in the inspector's judgment, a component is within one grade number of the load order specification, the component is passed, and its sample mixed with the others in that sublot. This is similar to quartering barges, except that no numerical data are collected. Actual inspections of components for critical factors (particle size, moisture) could provide a more precise sublot analysis that would not require the cu-sum plan for error computation. Smaller sublot standard deviations would also allow the shipper to target a quality closer to the grade limit and still have a lesser risk of loading off-grade grain.

There are no inspection plans in effect for truck, railcar, or barge inspection. As described before, sampling plans do require multiple samples to be composited to make inspection samples. This reduces sampling errors but not analytical errors. The same appeal procedure is available for interior inspections as for export inspections. The effect of inspection error is less in interior inspections because the domestic market uses discount schedules to reduce the price of substandard lots. At export, quality must meet grade or the grain is not loaded.

3.8.2. Accuracy and Standardization

There is great difficulty in estimating variability introduced by sampling. Specific sampling and sample handling procedures are different in this regard. Furthermore, there must be an analysis to establish quality; the analysis error and the sampling error are hard to separate. Comparative data from two separate samplings yield some insight, however, into the relative importance of sampling error.

Table 3-3 presents such data for a truck-sampling study of corn and soybeans. These were the data used to check the elevator sampling plan discussed earlier. Statistical theory states that sampling error should be reduced by increasing sample numbers, in proportion to $(1/n)^{0.5}$. The two-sample plan came reasonably close to theory for the Official grade factors. More importantly, certain factors obviously were more prone to sampling errors. As a percentage of mean value by the pelican, the standard deviations between pelican and probe were much larger for the particle-size factors and breakage susceptibility. Similar data have been reported in other studies (Hurburgh and Moechnig, 1984; Hurburgh, 1984). Therefore, breakage susceptibility may be a difficult factor to use for pricing, whereas the nutrient measures will not.

Ongoing standardization of sampling methods is nearly impossible. The only practical standardization is strict adherence to consistent methods and plans. In at least two cases, (truck probe approvals and DT sampler approvals), a potentially superior method must be checked against an inferior method. The data supporting sampling plans are limited, especially for barge and railcar sampling.

COMPARISON OF PROBE-SAMPLING METHODS, CORN

Quality factor	One probe per load (16 loads)				Two probes per load (22 loads)				Variability ratio, s_{d1}/s_{d2}
	Pelican		Probe minus pelican		Pelican		Probe minus pelican		
	Average	Std. dev.	Average	Std. dev., s_{d1}	Average	Std. dev.	Average	Std. dev., s_{d2}	
*Moisture, %	20.00	3.17	−0.41†	0.592	18.72	4.47	0.28†	0.577	0.975
*Test weight, lb/bu	53.70	3.13	0.00	0.837	55.00	2.53	−0.20†	0.395	0.472
*Broken corn, foreign material, %	0.59	0.34	0.41†	0.299	0.68	0.39	0.49†	0.238	0.796
Breakage susceptibility, %	13.20	5.40	−1.90†	3.025	12.60	5.27	1.00‡	3.258	1.077
Protein, % basis 15.5% moisture	8.27	0.95	0.12	0.466	7.90	0.76	−0.18‡	0.244	0.524
Oil, % basis 15.5% moisture	3.70	0.31	0.16	0.335	4.10	0.42	0.04	0.283	0.845
Average ratios:									
U.S. Grade factors or Official Criteria									0.748
All factors									0.760

*U.S. grade factors or Official Criteria
†Different from 0.0 (P= 0.05)
‡Different from one-probe value (P= 0.05)

COMPARISON OF PROBE-SAMPLING METHODS, SOYBEANS

Quality factor	One probe per load (20 loads)				Two probes per load (20 loads)				Variability ratio, s_{d1}/s_{d2}
	Pelican		Probe minus pelican		Pelican		Probe minus pelican		
	Average	Std. dev.	Average	Std. dev., s_{d1}	Average	Std. dev.	Average	Std. dev., s_{d2}	
*Moisture, %	10.84	1.70	−0.19	0.476	11.00	2.43	−0.27†	0.315	0.662
*Test weight, lb/bu	57.38	0.57	0.31†	0.399	57.13	0.76	0.36†	0.390	0.977
*Foreign material, %	0.59	0.54	0.20†	0.376	0.78	0.50	−0.01‡	0.345	0.918
*Splits, %	1.41	0.91	1.04†	0.677	2.00	1.57	0.77†,‡	0.464	0.685
*Damage, %	0.38	0.17	−0.04	0.295	0.58	0.41	0.09	0.299	1.014
Protein, % basis 13.0% moisture	34.19	0.51	−0.04	0.315	34.76	0.82	0.04	0.390	1.238
Oil, % basis 13% moisture	19.93	0.26	−0.28†	0.236	19.17	0.43	−0.17†,‡	0.213	0.903
Average variability ratios:									
U.S. Grade factors or Official Criteria									0.851
All factors									0.914

*U.S. Grade factors or Official Criteria
†Different from 0.0 (P= 0.05)
‡Different from one-probe value (P= 0.05)

Table 3-3. Comparison of probing methods and the pelican for corn and soybeans. (Hurburgh, 1987c)

3.8.3. Problems in sampling.

1. The information on the relative contribution of sampling and analytical error has not been aggregated.
2. Misunderstanding and mistrust of loading plans.
3. Some sampling methods unable to provide complete samples.
4. Poor sampling practices at country elevators.
5. Hand probe not accurate but used as a standard method.

3.8.4. New technologies

There have been few new sampling technologies introduced in the past five years. The last major innovation was the core-type mechanical probe, first marketed in 1978. DT samplers were introduced in the early 1960's. In recent years, changes have been refinements of the mechanics and reliability of existing designs. Mechanical probes generally have displaced hand probes at country elevators. In 1980, 80% of Iowa elevators had a mechanical probe.

There is no DT sampler practical for use at a country elevator. A DT requires that the handling system be cleaned between lots. Emptying dump pits between loads at country elevators would drastically slow down receiving operations. Furthermore, many operators maintain that they need to see the grain before it is dumped even though the actual test results are not available until later. There is one simple new sampler that might be used in the dump pit of an elevator. Grain flows over a

PVC pipe with large holes in the top side. Periodically a piston clears out the entrapped grain. It was not designed for pit use but could be adapted.

Expanded grain testing presents a dilemma for sampling. Presumably any new criteria would require grain to be more precisely segregated; thus, the need to know test results before dumping. Origin grades make advance knowledge possible at all points except the country elevator. But additional testing also puts more pressure on the representativeness of samples. Presumably, there would be more price-determining factors, and fewer of them would automatically be above discount levels. The placement of any factor on a continuous pricing scale, such that premiums or discounts would always be applied, would further increase the need for representative sampling.

3.8.5. Assessment of needs

As usual, the focal point for new technology must be the country elevator. If test results are not required before the load is dumped, then a DT type sampler at the receiving pit would be a major benefit. If test results must be available immediately, then probe sampling procedures need to markedly improved. A basis for such improvements is available.

Particle-size factors probably will remain the most difficult to sample. Compositional factors do not seem to be a major problem for sampling. Therefore, the testing of new sampling equipment and procedures can be limited to the easily measurable particle-size factors. If a procedure improves sampling for particle-size factors, it will improve sampling for all factors.

In the near term, any research on sampling procedures for the country elevator will have to be done without the prospect of immediate reward. The levels of most current grade factors are below limits at the farm level, which means that there is less incentive to be concerned with sampling each load accurately. The work should proceed, however, because the introduction of new factors will instantly trigger a demand for more information on sampling and testing. Organizations close to growing areas seem best suited for this work inasmuch as it is, by nature, on-site oriented.

A comprehensive review of sampling errors should be undertaken. A generalized variance model could be developed, then modified to fit individual sampling situations. In this way, a quantitative estimate of sampling variability could be obtained for each factor, an estimate that should be combined with analytical variability to develop realistic OC curves and loading plans. There are considerable data available, but much is fragmentary. Much information on sampling errors is contained in data collected for other reasons, with sampling error being part of the experimental errors or residuals. This review would be best done by USDA/FGIS because they have the greatest access to inspection information and the scientific literature.

Clearly an alternative is needed for the hand probe. There will always be situations in which stationary grain must be sampled by hand. The current compartmented probe can be improved upon. It collects excess foreign material, and it is difficult to force into deep grain. Barge probes are 12 ft long but often cannot be pushed in to full depth by one person.

The Commitment to Quality report emphasized the need for a barge loading (not sampling) plan. Participants realized that discouraging the use of probe grades for barges would only partly solve deterioration and deceptive loading problems. The relatively lengthy storage times for barge shipments magnify the effects of nonuniformity, especially moisture nonuniformity. If grain has expended most or all of its shelf life in domestic barge transit, further deterioration in ocean transit is virtually assured. To date, no action has been taken on the barge loading plan, although little if any new data will be needed. As a starting point, the quartering strategy would seem adequate, with moisture and the relevant particle-size factor(s) being determined four times during barge loading. A full grade would not be necessary.

The controversy over cu-sum needs to be resolved. Current debate has focused on compromise and acceptability to shippers.

The Woodall report was inadequate in its assessment of overall variability. A broader view of inspection errors and the potential remedies must be undertaken. A presumption of Woodall was that current procedures for components and sublots would be retained. Further, as Woodall pointed out, the ultimate objective of the shiploading plan has never been defined. Is it to obtain an accurate average? Uniformity within some preset limits? Avoidance of loading any off-grade grain? Protection for the shipper from variability? These are both technical and merchandising questions. They must be addressed by a collective effort of operations experts, economists, and statisticians. Until we define in technical and business terms, what is expected of the plan, changes will remain reactions to controversy, and the plan will continue to be a source of concern to U.S. grain customers.

4. TECHNICAL ISSUES FACING GRAIN INSPECTION

4.1. Standardization of Test Results

Standardization (uniformity) is critical to grain inspection. Ideally, uniformity must extend from country elevator to foreign buyer. Standardization procedures in the Official system have been discussed by factor in the previous section. The point at issue is not necessarily the validity of FGIS standardization methods, but their extension to unofficial inspection. These are left to the discretion of states. Some states monitor moisture measurement, others have no tests at all. Private inspection companies are becoming more and more involved with export trades, as contractual provisions show. It would be very difficult for a grain merchant in Iowa to determine what protein value an independent lab in New Orleans would assign to a soybean shipment, should it be loaded for Taiwan. Yet, that is precisely the situation today.

When a measurement becomes part of general commerce, there is no place for differing basic standards. Merchants have realized the need for uniformity as much as government. Professional societies, for example American Oil Chemists' Society (AOCS) and American Association of Cereal Chemists (AACC), have check-test services based on their particular version of methods. These services originated from a need in the industry to regulate itself. However, it is not reasonable to expect private services to be capable of serving the entire market if descriptive testing becomes widespread.

The conclusion is that, for each quality test used in general commerce, there must be a nationally accepted reference method. This method must be developed by consensus, not governmental fiat. Once established, all applications in commerce must be somehow traceable to the national standards. As a matter of personal opinion, I believe that FGIS, or a group of agencies coordinated by FGIS, must be the keepers of the national grain reference standards. This will require consistent effort and scientific support by FGIS. Failure to maintain accuracy will lead to more controversies similar to that for wheat protein. Scientific support must be linked to public information programs so that the market is fully aware of the limitations of its testing devices.

4.2. Operational Criteria for New Technologies

As the relevance of additional quality factors becomes evident, criteria must be established to govern the design of rapid test instruments. The country elevator probably will be the most difficult place to introduce new technology. The time constraints are severe, and the resources, both human and capital, are limited. The country elevator is the key, however, to improving U.S. grain quality.

All the major decisions determining future quality are made at the farm and country elevator levels. Genetics and production practice are farmer decisions. Storage and drying are shared between farmers and country elevators. Export quality problems that have received so much attention are in reality simply natural consequences of previous grower and/or country elevator operations aided perhaps by the tolerant nature of the current Standards. If intrinsic (composition, hardness) and future physical quality is determined at the local level, then incentives for change must also exist at that level. Incentives require testing. Complete testing at the country elevator is necessary for the USA to be successful in upgrading grain quality or in merchandizing grain according to quality.

The demands of the country market should be paramount even to those concerned only with Official inspections. The important issues are speed, repeatability, reasonable cost, accuracy, durability, standardization, and capability to handle wide ranges in quality. Every test, existing or potential, will have values that can be assigned to these key parameters. Development of new Official procedures should be done in such a way as to meet the needs of the country elevator as well as the Official inspection agency.

An example serves to illustrate the point. Iverson (1983) reported FGIS' initial efforts to develop soybean NIR calibrations for protein and oil content. The grinder selected required 1-3 minutes per sample and would not grind the 14-20% moisture soybeans often encountered at country elevators. Furthermore, it would not grind corn, which meant that any elevator handling corn and beans would have to have two grinders. The procedures simply were incompatible with country market conditions.

Evaluation of potential new technologies must be done from a total system viewpoint; otherwise, resources are wasted and credibility undermined. Furthermore, specifications should focus on results rather than on design parameters for equipment. Performance based specifications allow for, indeed encourage, the development of new technologies, but while design related specifications do not.

The market has two basic measurement conditions for accepting a new quality factor or a new technology--credibility of data and marketwide consistency. Credibility is difficult to recoup once damaged. Consistency cannot be obtained without a total system plan for application and standardization.

5. SUMMARY AND CONCLUSIONS

Effective incentives for improved quality will require accurate inspection at all points in the market chain. The pressure point for inspection will be the country elevator because 1) grain flow is fastest there (in terms of individual lots received) and 2) the farmer controls most important quality decisions and therefore must see incentives for improvement.

For Official grade factors, the Official system is reasonably well standardized, but Official methods are not always practical at country points. Further descriptive testing will force country elevators to reassess needs for analysis equipment and personnel, at some cost to growers. The trend to larger farms and fewer growers but higher yields will increase the needs for speed and accuracy in inspection. An important question yet unaddressed is how the grower will assess quality on the farm to make management decisions. If the grower is unable to differentiate or chooses not to, much of the value of end-user-oriented testing will be lost.

Several general concepts emerge common to all quality factors.

1. There is a greater need for coordination and communication of research effort. Research has been generally individualized without a clear set of established goals. As a result, resource efficiency has not been as good as it could have been.

2. Nationally accepted standard references and trading practices must exist for all quality factors, present and future. A greater level of scientific expertise will be needed at the Federal level to maintain the credibility and consistency of U.S. grain quality tests.
3. Objective technology should replace subjective assessments wherever possible.

Specific inspection technology issues of most importance are:

1. Development of automated composition analysis.
2. Simplification of particle-size determination.
3. Objective technology for damage and odor measurement.
4. Clear interpretation of hardness, stress cracks, and breakage susceptibility.
5. Nationally uniform moisture-meter calibrations.
6. Single-kernel moisture test
7. Objective wheat classing and hardness tests.
8. Resolution of controversies surrounding loading plans for vessels and barges

If the United States were required in the near term to identify and deliver higher-quality grain, we probably could meet the demand insofar as the basic soundness factors (FM, damage, moisture) are concerned. In end-use-related factors, we probably could not, at least not efficiently. At the present pace of technological and political progress, it would require 5-10 years for the USA to have composition, kernel moisture, optical scanning, and automatic wheat classing in routine service. Research resource commitments in the order of $10-$20 million would accelerate technological progress considerably. The generally accepted 10 to 30-cent-per-bushel incentive required for change in the grain market would provide for installation of equipment on a gradual basis.

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